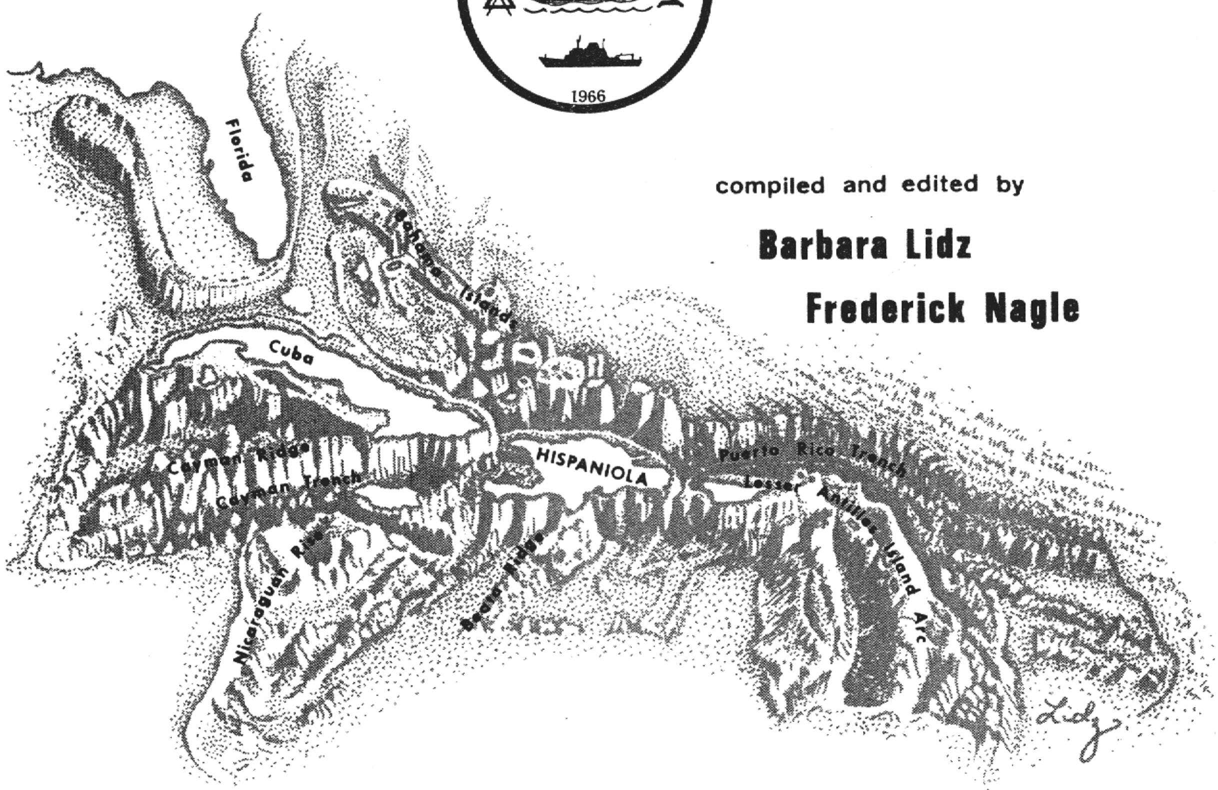
HISPANIOLA: TECTONIC FOCAL POINT OF THE NORTHERN CARIBBEAN~ Three Geologic Studies in the Dominican Republic

Frederick Nagle, H. Currie Palmer, and Gustavo A. Antonini

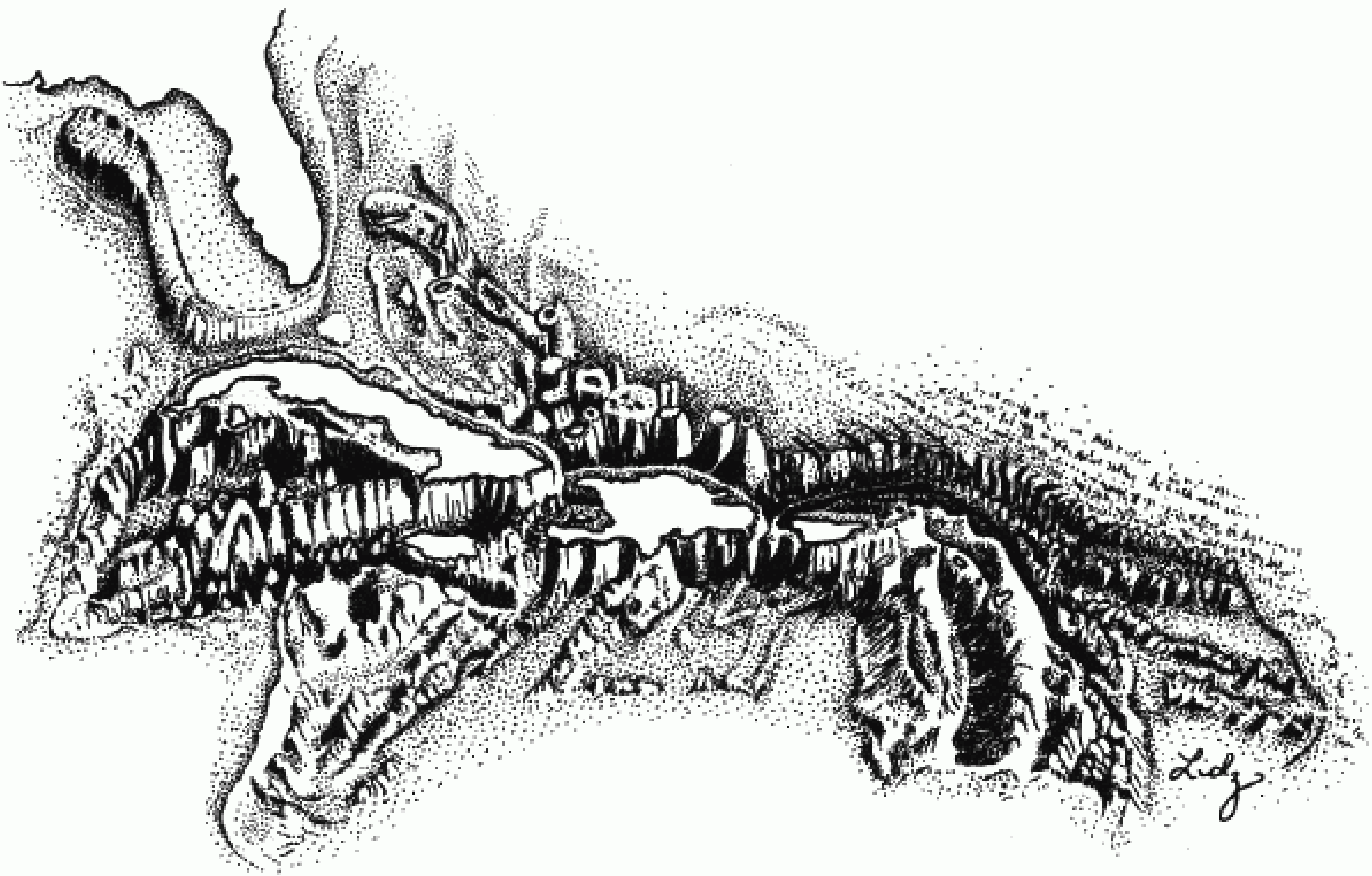


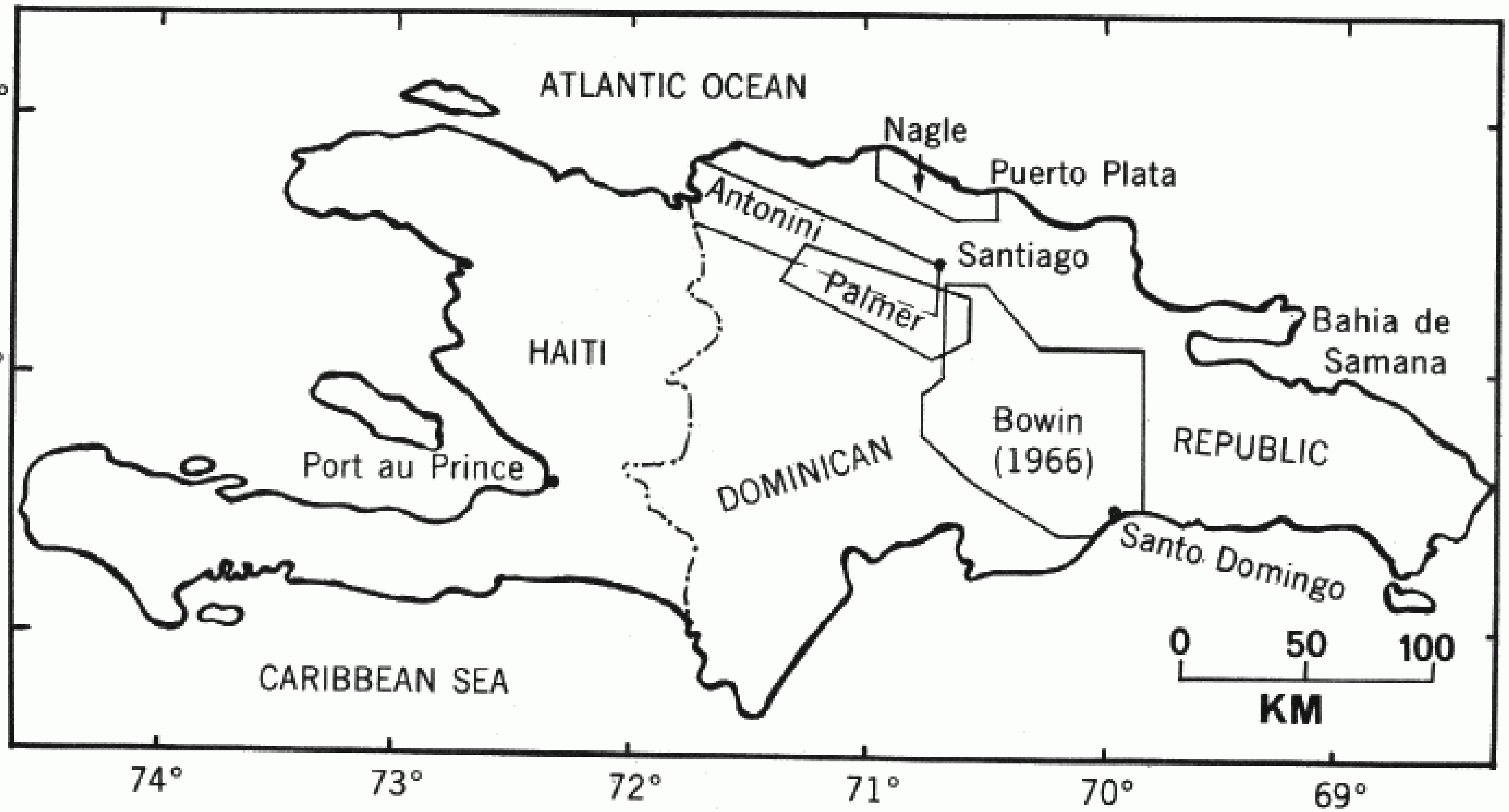
compiled and edited by

Barbara Lidz

Frederick Nagle

March 1979





INDEX MAP OF AREAS STUDIED. NAGLE, PALMER, ANTONINI (THIS REPORT), BOWIN (1966).

HISPANIOLA: TECTONIC FOCAL POINT OF THE NORTHERN CARIBBEAN

THREE GEOLOGIC STUDIES IN THE DOMINICAN REPUBLIC

Frederick Nagle, University of Miami

H. Currie Palmer, University of Western Ontario

Gustavo A. Antonini, University of Florida

Compiled and Edited

by

Barbara Lidz and *Frederick Nagle*

Miami Geological Society
4600 Rickenbacker Causeway
Miami, Florida 33149

March 1979

DEDICATION

Annette and Harry Hess

This volume lists for $12.50. See inside back cover for complete Miami Geological Society publication list.

VOLUME CONTENTS

PREFACE

During the summer of 1980, the 9th Caribbean Geologic Conference plans to meet on the island of Hispaniola in Santo Domingo, Dominican Republic. This event will bring to that island, for the first time in history, a large number of geologists, geographers, mining engineers, and other professional scientists from many countries, many of whom will discover unsolved geologic problems of interest in a country of great economic promise.

Hispaniola is the last Caribbean island having "geologic frontiers," i.e., great expanses of terrain unknown geologically. During the past five years, it has become evident to Caribbean geologists that this island will become a focal point for geologic work in the Caribbean (Intergovernmental Oceanographic Commission, 1975; Burke and Fox, 1977; Weaver, 1977). As noted in Weaver (1977, p. 137), "Hispaniola is the hub, or "structural knot," where the Cayman Trench, the Nicaraguan Rise, the Cayman Ridge, the Puerto Rico Trench, the eastern Greater Antilles, the Beata Ridge and the Bahamas-Cuba intersection zone meet.... Thus this region probably holds the key to a proper tectonic interpretation of the northern margin of the Caribbean plate" (Fig. A).

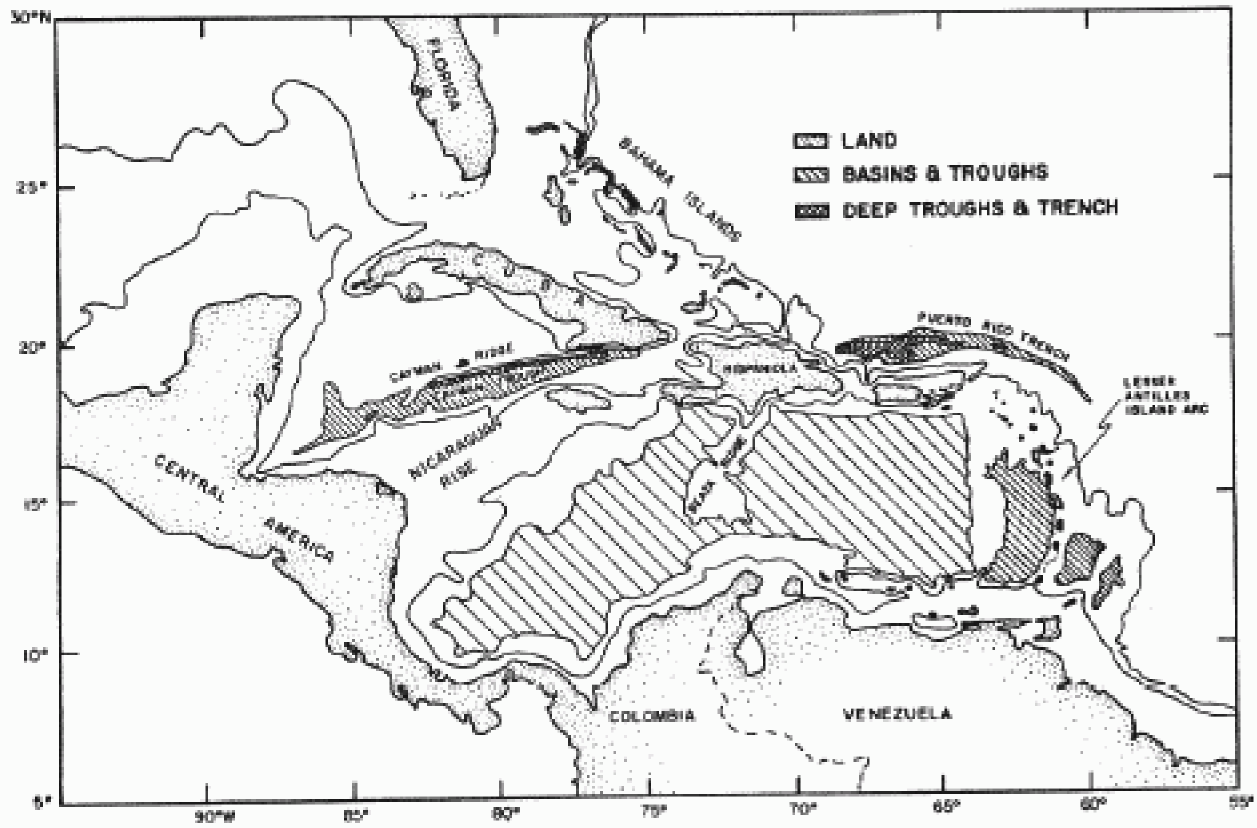


Figure A. Physiographic features of the Caribbean (after Fink, 1968).

During the past 20 years, Hispaniola has begun production from several important ore deposits; bauxite is being mined by Reynolds Haitian Mines in Haiti, and by Alcoa in the Dominican Republic. By virtue of the operations of Falconbridge Dominicana, the Dominican Republic is now the fourth ranking producer of nickel among non-communist nations, and the country currently has the largest open-pit gold mine in the world with a projected annual production of 350,000 oz of gold (Sisselman, 1977). Some of the world's finest amber deposits are mined in northern Dominican Republic (Zahl, 1977). Potential mineral development for the island is not fully known, but exploration has discovered prospects for gold, silver, titaniferous sands, manganese, molybdenum and copper. For a review of the mineral situation, the reader is referred to Guild and Cox (1977), Llinas (1977), Sisselman (1977), and Kesler (1978). Although there is no current oil production on the island, several companies were actively exploring during 1977-1978 (Amato, 1978). Mineral and petroleum interest in the island is increasing, and the mineral developments since 1958 have already helped relieve strains on what was primarily a sugar economy.

With these developments in mind, we have gathered three geologic studies in this volume, done in the Dominican Republic and completed prior to the rise and general acceptance of the plate tectonics and sea-floor spreading concepts. The three papers are condensations of unpublished Ph.D. theses; two from Hess' Princeton group (Palmer, 1963; Nagle, 1966) are geologic in content, and a third (Antonini, 1968) emphasizes physical geography but is important to geologists in that it contains geologic information which overlaps with and builds upon Palmer's study. All three writers were in agreement that their manuscripts should be left in the context of the time during which they were written, so that no attempt has been made to adapt them to fit popular tectonic models or to incorporate the later studies discussed below.

Palmer's study area adjoins the area studied earlier by Bowin (1960, 1966; this volume, frontispiece), and these two share with Antonini an attempt to build a common stratigraphic column. In this publication we have maintained the precedent set by Cooke (*in* Vaughan *et al.*, 1921) concerning the spelling of Tabera Formation, although that unit was named after the town, Tavera, south of Santiago. Nagle's study area (this volume, frontispiece) is on the north coast of the island, separated from the others by the Cordillera Septentrional, so that his stratigraphic column was developed independently from the others. Both Palmer's and Nagle's field work was done at a time when good topographic maps were not available, the road network was poor and the stratigraphic column unknown except for portions of the Tertiary. Palmer replotted his geologic map for this publication on topographic maps (Series E733), which became available during the late 1960's. The newer topographic maps were also used as a base map by Antonini. Nagle's map has much less control and was left in the original state, since later trips (post-1961) by him to the Puerto Plata area indicated that new exposures in the area west of Maimon Bay might show a need to remap that area.

Special problems from Nagle's paper have been published previously (Nagle, 1971a, 1972, 1974). Antonini has published a shortened version of his paper (Antonini, 1972). None of Palmer's paper has been published.

Since the field work for the studies in this volume were completed, several publications dealing with the geology of the Dominican Republic and Hispaniola have appeared. They are important to mention now, so as to set in time context the papers published herein. Several were mentioned in a review prepared by Nagle, which was published in a condensed form in Burke and Fox (1977, p. 14-16).

Over a number of years, Nagle has developed the idea of Cretaceous southward subduction under the north coast of Hispaniola with associated mélange production and metamorphism (Nagle, 1969, 1970, 1971a, 1971b, 1972, 1974), a process which involves rocks from the Puerto Plata area on the north coast and those mapped by Bowin (1960, 1966), Palmer (this volume) and Antonini (this volume) in central Dominican Republic. Perfit *et al.* (1978) describe igneous and metamorphic rocks dredged from the Puerto Rico Trench, similar to those found along the strike on the north coast of the Dominican Republic. They have extended the dual metamorphic belts described by Nagle (1974) 300 km farther to the east.

Bowin (1975) has suggested the possibility of an earlier period of northward subduction, preceding the episode of southward subduction, to explain relationships in the central portion of the country. Both of these models and others are speculative, however, because of lack of radiometric and paleontologic ages, especially along the north coast. Nagle is currently attempting to obtain K-Ar radiometric ages for igneous rocks in that region. Bracey and Vogt (1970) have suggested that part of northeastern Hispaniola is currently being underthrust from the north, based on earthquake distribution and first-motion studies, whereas Ladd *et al.* (1977) propose late Tertiary subduction from the south, under the Muertos Trench, from seismic reflection records and suggest that this subduction may still be going on today. There is the possibility, then, of four different subduction events affecting the geology of Hispaniola.

Blesch (1967) compiled the most complete geologic map of the Dominican Republic for that time. Among regional studies completed since then, Llinas (1972), Kesler and Speck (1973), Feigenson and Lewis (1977), and Michael and Millar (1977) lend hope to the possibility of a new compilation.

The works of Bowin (1968, 1971, 1975, 1976) and Reblin (1973) summarize the gravity data of Hispaniola. There has been no published magnetic survey of the island.

Of great importance to the later tectonic history of the island is the distribution of post-Eocene volcanic rocks, most recently commented upon by MacDonald and Melson (1969) and Donnelly (1971). The distribution of these rocks is not well known and, therefore, they cannot yet be related to the purported late Tertiary subduction events (Bracey and Vogt, 1970; Ladd *et al.*, 1977).

Both Weyl (1966) and Khudoley and Meyerhoff (1971) contain useful geologic data on Hispaniola, but the latest and most complete review of the geology of the island is that by Bowin (1975). Since that time, Kesler and his colleagues (Kesler *et al.*, 1975; Kesler *et al.*, 1977; Kesler and Sutter, 1977) have added many radiometric ages and chemical analyses of intrusive rocks to published geologic history of the island. One result of their work is that attention has been focused on the oldest rocks (120 m.y.); at the time they were formed, there was apparent simultaneous igneous activity and regional metamorphism.

Currently, there are several important geologic studies in progress. John Lewis and his students at George Washington University have mapped several key areas in the western Cordillera Central in collaboration with scientists at Universidad Católica Madre y Maestra in Santiago, Dominican Republic. Brian Redmond (Wilkes College) is completing a sedimentological study in the Cordillera Septentrional and has "rediscovered" basement (volcanic, metavolcanic, and plutonic) rocks near the Pedro Garcia area in the Septentrional range. These basement rocks may one day provide a link between similar rocks already known in the Puerto Plata area (Nagle, 1966, 1974, this volume) and those in the areas mapped by Bowin (1960, 1966), Palmer (1963, this volume), and Antonini (1968, this volume). John Lewis and Steve Kesler (University of Michigan) are working on the petrology, major and minor element geochemistry, and Sr isotope data of nearly all known major plutons of the Cordillera Central. John Saunders (Museum of Natural History, Basel, Switzerland) has launched an international effort to reexamine the classic Tertiary Cibao sections. Steve Kesler has also been working on the petrology and distribution of the Los Ranchos Formation, a unit critical to the interpretation of the Early Cretaceous and which, incidentally, is also the host unit of the gold deposit mentioned earlier. James Joyce (Northwestern University) is engaged in a structural study of the metamorphic rocks of the Samana; John Weaver and Alan Smith (University of Puerto Rico, Mayaguez) have done initial reconnaissance in the same region in preparation for detailed petrologic work and mapping.

Mining companies, oil companies, and Dominican governmental agencies have compiled data which have not been released for publication. With support from the Dominican government, mining companies, and the British government, the Universidad Católica Madre y Maestra has initiated a training program for students of college level geology, as well as geological, metallurgical, and mining engineering.

It is apparent that the stimuli from academic interest, rapid economic development, and an impending international geologic conference will open a new age of exploration in Hispaniola.

Frederick Nagle

March 1979
Coral Gables, Florida

PREFACE REFERENCES

Amato, F.L., 1978, Petroleum developments in South America, Central America, Mexico and Caribbean area in 1977: Amer. Assoc. of Petroleum Geol., Bull., vol. 62, no. 10, p. 2044-2110.

Antonini, G.A., 1968, Processes and patterns of landscape change in Linea Noroeste, Dominican Republic: Unpublished Ph.D. Dissertation, Columbia University.

________, 1972, Morphology and surficial geology of northwestern Dominican Republic: *in* Caribbean Geol. Conf., 6th, Trans., C. Petzall, ed., Caracas, p. 89-95.

Blesch, R.R., 1967, Mapa geologico preliminar, República Dominicana: *in* Reconocimiento y evaluación de los recursos naturales de la República Dominicana, vol. II, Washington, D.C., Panamerican Union.

Bowin, C.O., 1960, Geology of central Dominican Republic: Unpublished Ph.D. Dissertation, Princeton University. 211 p.

________, 1966, Geology of central Dominican Republic: a case history of part of an island arc: Geol. Soc. Amer. Memoir 98, p. 11-84.

________, 1968, Geophysical study of the Cayman Trough: Jour. Geophys. Research, vol. 73, no. 16, p. 5159-5173.

________, 1971, Some aspects of the gravity field and tectonics of the northern Caribbean region: Caribbean Geol. Conf., 5th, Trans., Queens College Press, Geol. Bull. 5. 6 p.

________, 1975, The geology of Hispaniola: *in* Ocean Basins and Margins, vol. 3, Gulf of Mexico and Caribbean, A.E.M. Nairn and F.G. Stehli, eds., Plenum Press, New York.

________, 1976, Caribbean gravity field and plate tectonics: Geol. Soc. Amer. Spec. Paper 169. 79 p.

Bracey, D.R. and P.R. Vogt, 1970, Plate tectonics in the Hispaniola area: Geol. Soc. Amer., Bull., vol. 81, p. 2855-2860.

Burke, K. and P.J. Fox, 1977, Caribbean problems, a report on a workshop held to help identify important geological problems related to the evolution of the Caribbean: Albany, N.Y., State University of New York, Albany. 44 p.

Donnelly, T.W., 1971, A late Cenozoic volcanic center in the Dominican Republic: (Abs.) Caribbean Geol. Conf., 6th, Margarita, p. 9.

Feigenson, M.D. and J.F. Lewis, 1977, Petrography and geochemistry of the Loma de Cabrera Batholith, Dominican Republic: (Abs.) Caribbean Geol. Conf., 8th, Curacao, p. 46-47.

Fink, L.K., Jr., 1968, Geology of the Guadeloupe region, Lesser Antilles island arc: Ph.D. Dissertation, University of Miami. 121 p.

Guild, P.W. and D.P. Cox, 1977, Mineral resources of the Caribbean: *in* Geology, Geophysics and Resources of the Caribbean, J.D. Weaver, ed., Intergovernmental Oceanographic Commission, UNESCO, University of Puerto Rico, Mayaguez. 148 p.

Intergovernmental Oceanographic Commission, 1975, Workshop Report 5: IDOE International Workshop on the Marine Geology and Geophysics of the Caribbean Region and its Resources, Kingston, Jamaica, 17-22 February 1975: IOC, UNESCO, Place de Fontenay, Paris. 38 p.

Kesler, S.E., 1978, Metallogenesis of the Caribbean region: Jour. of the Geol. Soc., vol. 135, p. 429-441.

Kesler, S.E., L.M. Jones, and R.L. Walker, 1975, Intrusive rocks associated with porphyry copper mineralization in island arc areas: Econ. Geol., vol. 70, p. 515-526.

Kesler, S.E. and R.C. Speck, 1973, Plagioclase-bearing dunite from the western Cordillera Central, Dominican Republic: Caribbean Jour. Sci., vol. 13, p. 1-7.

Kesler, S.E. and J.F. Sutter, 1977, Progress report on radiometric age determinations in the Caribbean region: (Abs.) Caribbean Geol. Conf., 8th, Curacao, p. 85-86.

Kesler, S.E., J.F. Sutter, L.M. Jones, and R.L. Walker, 1977, Early Cretaceous basement rocks in Hispaniola: Geology, vol. 5, p. 245-247.

Khudoley, K.M. and A.A. Meyerhoff, 1971, Paleogeography and geological history of Greater Antilles: Geol. Soc. Amer. Memoir 129. 199 p.

Ladd, J.W., J.L. Worzel, and J.S. Warkins, 1977, Multifold seismic reflection trends from the northern Venezuela Basin and the north slope of the Muertos Trench: *in* Island Arcs, Deep-Sea Trenches, and Back-Arc Basins, M. Talwani and W.C. Pitman, III, eds., Maurice Ewing Series I, Amer. Geophys. Union, Washington, D.C., p. 41-56.

Llinas, R.A., 1972, Geologia del area Polo-Duverge, Cuenca de Enriquillo, Codia: Publication of Colegio Dominicano de Ingenieros, Arquitectosa y Agrimensores, pt. 1 in no. 31, p. 55-65, and pt. 2 in no. 32, p. 40-53.

Llinas, R.A., ed., 1977, Primer seminario sobre el sector minero, Santo Domingo, July 4-8, 1977, Auspiciado por Secretario de Industria y Comercio y Direccion General de Mineria, Dominican Republic.

MacDonald, W.D. and W.G. Melson, 1969, A late Cenozoic volcanic province in Hispaniola: Caribbean Jour. Sci., vol. 9, p. 81-91.

Michael, R.C. and G. Millar, 1977, Tertiary history of the southwestern flank of the Cordillera Central, Dominican Republic: (Abs.) Caribbean Geol. Conf., 8th, Curacao, p. 85-86.

Nagle, F., 1966, Geology of the Puerto Plata area, Dominican Republic: Unpublished Ph.D. Dissertation, Princeton University. 171 p.

________, 1969, Serpentinites and serpentinite breccias in north central Dominican Republic: Geol. Soc. Amer. Spec. Paper 115, p. 280-281.

________, 1970, Serpentinites and metamorphic rocks at the Caribbean boundaries: (Abs.) Geol. Soc. Amer., Abs. with Program (Ann. Mtg.), vol. 2, no. 7, p. 633.

________, 1971a, Geology of the Puerto Plata area, Dominican Republic, relative to the Puerto Rico Trench: Caribbean Geol. Conf., 5th, Trans., Queens College Press, Geol. Bull. 5, p. 79-84.

________, 1971b, Caribbean geology, 1970: Bull. Marine Sci., vol. 21, p. 375-439.

________, 1972, Chaotic sedimentation in north-central Dominican Republic: *in* Studies in Earth and Space Sciences (Hess volume), R. Shagam and others, eds., Geol. Soc. Amer. Memoir 132, p. 415-428.

________, 1974, Blueschist, eclogite, paired metamorphic belts, and the early tectonic history of Hispaniola: Geol. Soc. Amer., Bull., vol. 85, p. 1461-1466.

Palmer, H.C., 1963, Geology of the Moncion-Jarabacoa area, Dominican Republic: Unpublished Ph.D. Dissertation, Princeton University. 256 p.

Perfit, M.E., B.C. Heezen, M. Rawson, and T.W. Donnelly, 1978, Chemistry, origin and tectonic significance of metamorphic rocks from the Puerto Rico Trench: (preprint of paper submitted to Marine Geol., 47 p.).

Reblin, M.T., 1973, Regional gravity survey of the Dominican Republic: M.S. Thesis, University of Utah. 129 p.

Sisselman, R., 1977, Hispaniola: an island with a mining future: Engineering and Mining Jour., p. 133-149.

Vaughan, T.W., W. Cooke, D.D. Condit, C.P. Ross, W.P. Woodring, and F.C. Calkins, 1921, A geological reconnaissance of the Dominican Republic, geological survey of the Dominican Republic: Memoirs, vol. 1, prepared by the U.S. Geol. Survey, Washington, D.C. 268 p.

Weaver, J.D., ed., 1977, Geology, Geophysics and Resources of the Caribbean, Report of the IDOE Workshop on the Geology and Marine Geophysics of the Caribbean Region and its Resources, Kingston, Jamaica, 17-22 February 1975, Intergovernmental Oceanographic Commission, UNESCO, University of Puerto Rico Press, Mayaguez. 150 p.

Weyl, R., 1966, Geologie der Antillen, Band 4, Beiträge zur Regionalen Geologie der Erde, H.J. Martini, ed., Gebrüder der Borntrager, Berlin. 410 p.

Zahl, P.A., 1977, Golden window on the past: Nat. Geographic Magazine, vol. 152, no. 3, p. 423-435.

GEOLOGY OF THE PUERTO PLATA AREA, DOMINICAN REPUBLIC

Frederick Nagle
Department of Geology
University of Miami
Miami, Florida 33124

CONTENTS

ILLUSTRATIONS

Figure

Plate

ABSTRACT

The 700 square km area of Puerto Plata in the north-central Dominican Republic contains extrusive and intrusive igneous rocks, as well as sedimentary and metamorphic rocks. The oldest are serpentinites, which represent basement upon which the pre-Paleocene Los Caños Formation was deposited and which occur as infaulted bodies of two textural types within this formation: a massive blocky serpentinite and a serpentinite breccia. Both are probably detached fragments of oceanic crust and reflect different primary crustal textures. Gabbros associated with the serpentinites and the Los Caños Formation are converted to rodingites in the vicinity of serpentinites. All contacts between gabbro bodies and the formation are faults; however, rodingites do intrude the serpentinites. Both gabbros and serpentinites were faulted into the Los Caños Formation before the Paleocene, and periodic upward movement of both rock types occurred through the Late Eocene. The Los Caños Formation, serpentinites and gabbros occur together near the core of the major antiformal structure in the area.

The Los Caños Formation consists of andesite flows and tuffs, with spilites and keratophyres near the base. Relic glassy textures indicate that the formation is submarine in origin. Its exact age is unknown, but it is overlain unconformably by the Paleocene Imbert Formation. Thickness of the Los Caños Formation is estimated at several km. Northeast of the town of Imbert, serpentinites faulted into the Los Caños contain large tectonic inclusions of glaucophane schist, actinolite schist and black marble, which probably represent lower Los Caños Formation or older rocks upfaulted with the serpentinites.

Lying unconformably above the Los Caños Formation is a 1 km-thick succession of fine-grained, graded-bedded, calcareous tuffs grading upward to vitric andesite and dacite tuffs, with rare interbedded green radiolarian cherts and thin, white, aphanitic limestones. This succession, the Imbert Formation, has been dated as Paleocene-to-Lower Eocene and is submarine in origin.

Middle Eocene rocks occur only as exotic blocks in the San Marcos olistostrome, a several hundred meter-thick chaotic clay unit containing boulders of various rock types ranging from Upper Cretaceous (Maestrichtian) to Middle Eocene in age. This unit was tectonically emplaced instantaneously in the Middle Eocene.

By early Late Eocene time, part of the area was above sea level, the older formations supplying the first stream-worn detritus to the Luperon Formation in the western portion of the map area. The Luperon is estimated to be 1 km thick and consists of a coarse basal conglomerate with an alternating sequence of calcareous, tuffaceous, graded-bedded sandstones and shales containing occasional interbedded bioclastic limestones.

The area was above sea level during the Miocene, and no rocks were formed except for the discontinuous reef-like Isla Limestone. Immediately to the south, east, and west, Oligocene-Miocene sediments were deposited in a marine basin. Following the Middle Miocene, uplift of the Cordillera Septentrional began, and a detached block of Miocene limestones slumped north to form Pico de Isabel de Torres.

The dominant structural feature in the Puerto Plata area is a broad, faulted antiform which trends N 55°W parallel to the north coast of the Dominican Republic and plunges to the northwest. Normal faulting, slumping, and gravity sliding were the major mechanisms of rock deformation within the mapped area.

On the basis of the lithologic and tectonic record of the Puerto Plata area, the writer suggests that the area represents a raised portion of the south flank of the present Puerto Rico Trench.

INTRODUCTION

Location

The area described in this report is located in the north-central part of the province of Puerto Plata along the north coast of the Dominican Republic. The intersection of geographic coordinates 19°45'N, 70°40'W lies on the southeast flank of Pico de Isabel de Torres about 3.2 km south of Puerto Plata, capital of the province and main city in the area (Plate I).

Methods and Terminology

During the summers of 1959, 1960, 1961, and spring of 1962, 11 months were spent in the Dominican Republic field mapping on aerial photographs (scale 1:60,000) taken by Spartan Air Service of Canada in January 1959. A semi-controlled base map constructed from the photos was used in the field as a compilation map and is reproduced here as Plate I.

Laboratory studies were carried out at Princeton University and were based upon approximately 1,000 hand specimens and 400 thin sections. Smear mounts on glass slides were x-rayed using cooper radiation with a Norelco diffractometer at the speed of 2°/minute.

Previous Work

There is no published geologic map of the Puerto Plata area known to the writer. The older reports of Gabb (1873) and Vaughan *et al.* (1921) are descriptive works on the geology of the country. Both reports are interesting mainly from an historical standpoint. In a paleontological study of the Tertiary foraminifera of the Dominican Republic, Bermudez (1949) reports a Middle Oligocene date from rocks 4 km southeast of Puerto Plata, a Middle Miocene date from rocks in a water well in Sosua, one Upper Eocene date and two Middle Oligocene dates from rocks northeast of El Mamey (5 km southeast of Imbert), as well as many Lower and Middle Miocene dates from rocks in the Cordillera Septentrional to the south of this area of study.

Acknowledgments

The author gratefully acknowledges the encouragement and counsel given by Professors H.H. Hess, J.O. Kalliokoski, and A.G. Fischer of the Department of Geology, Princeton University. Professor Hess suggested the project and visited the writer in the field.

The bulk of field support was extended to the author by Compania Petrolera Dominicana, William D. Pawley, President. Edward P. Pawley, General Manager, and A.A. Weymouth, Chief Geologist of Compania Petrolera, were of assistance in innumerable problems of logistics and support. The cooperation of the Instituto Cartografico Universitario directed by Ing. Jose Joaquin Hungria and the many personal favors extended by Dr. Pompilio Brouwer, Director General de Minas y Petroleo, were key factors in the success of the field work.

Offices of Compania Minera y Beneficiadora Falconbridge were kindly kept open to the author, and many personal favors were rendered by members of their staff during the writer's stay in the Dominican Republic. The generous hospitality extended on numerous occasions by the families of Tomas Pastoriza and Gustavo Tavares of Santiago are gratefully appreciated.

Field notes from initial reconnaissance work in the Puerto Plata area done by Carl Bowin in 1958 and Bowin's personal enthusiasm encouraged the author to begin this study. F.J. Sawkins and G.H. Ware provided able and enthusiastic assistance during the summers of 1960 and 1961, respectively. Much profit to the writer came from discussions with fellow graduate students at Princeton University, chiefly C. Bowin, H.C. Palmer, V.M. Seiders and Lynn

Grover, III. Validity of the stratigraphic column presented in Figure 1 is due largely to the efforts of P.J. Bermudez, W.S. Cole, and J.H. Johnson, who kindly identified fossils collected by the author.

Financial cost of the project was borne by National Science Foundation Grant G14217 to Princeton University. A portion of the field expenses was financed by Compania Petrolera Dominicana. The writer gratefully acknowledges a Woodrow Wilson Fellowship and a National Science Foundation Summer Fellowship held while at Princeton University.

STRATIGRAPHY

Figure 1 is a diagrammatic interpretation of the stratigraphic column in the Puerto Plata region. With the exception of the serpentinites, gabbros, and fault breccias, the stratigraphic sequence is entirely marine. Few of the successive units are in contact with one another, and the paleontological dates assigned to the various units may not indicate the oldest or the youngest rocks in their respective sequences.

LOS CAÑOS FORMATION

Introduction

The Los Caños Formation, named for the small settlement of Los Caños 2 km west of Maimon Bay, is the oldest formation in the Puerto Plata area. Its base is not exposed, but from the outcrop pattern it is presumed to lie on a basement of serpentinized peridotite and is overlain unconformably by the Imbert Formation of Paleocene-Early Eocene age. No diagnostic fossils were found in the Los Caños, so that its age, other than its stratigraphic position, is not known. It appears to occupy the core of a generally antiformal structure. The writer prefers the term 'antiform' as a descriptive term for this overall structure rather than the term 'anticline,' since the north flank and the core of the structure are allochthonous and not the result of folding about an axis.

The formation, composed of volcanic rocks, is exposed in sparse ordinarily badly weathered outcrops. Bedding is rarely observed, and hence, thickness of the Los Caños is largely a matter of conjecture, but it is probably several kilometers.

Mineralogy and Petrology of Los Caños Rocks

Thirty-five samples were studied in thin section and were grouped in the following categories, listed in approximate order of decreasing abundance: (1) crystal and lithic andesite tuffs; (2) hornblende andesite flows; (3) spilites; (4) feldspathic andesites (keratophyres?); and (5) pyroxene andesite flows. The spilites and keratophyres(?) are more abundant near the core of the antiform and hence appear to be generally lower in the section than the other types. Inasmuch as bedding is poorly developed in the formation, internal structural-stratigraphic relationships are poorly known.

The tuffaceous rocks are the most severely weathered in the Los Caños sequence. The most common variety (andesitic crystal-vitric tuff) is characterized by plagioclase fragments averaging 0.5 mm set in a matrix of devitrified glass converted largely to chlorite, calcite, and dusty magnetite. Occasional lithic fragments within this variety of tuff are tuffaceous themselves and in rare cases have the glassy vesicular appearance of devitrified pumice. They often have chloritized globules and shards, remnants of original glassy structure, and in two slides the glassy matrix curves around crystal and lithic fragments in an apparent flow structure.

The only pillow volcanic rock known in the Puerto Plata area occurs as a large (50 m x 20 m x 100 m) exotic block in the San Marcos olistostrome on the road between Puerto Plata and Imbert. Since other varieties of exotic volcanic blocks within the San Marcos are similar in mineralogy and texture to Los Caños volcanics, and no other ages of volcanic flow rocks are known in the Puerto Plata area, this block most likely belongs to the Los Caños Formation.

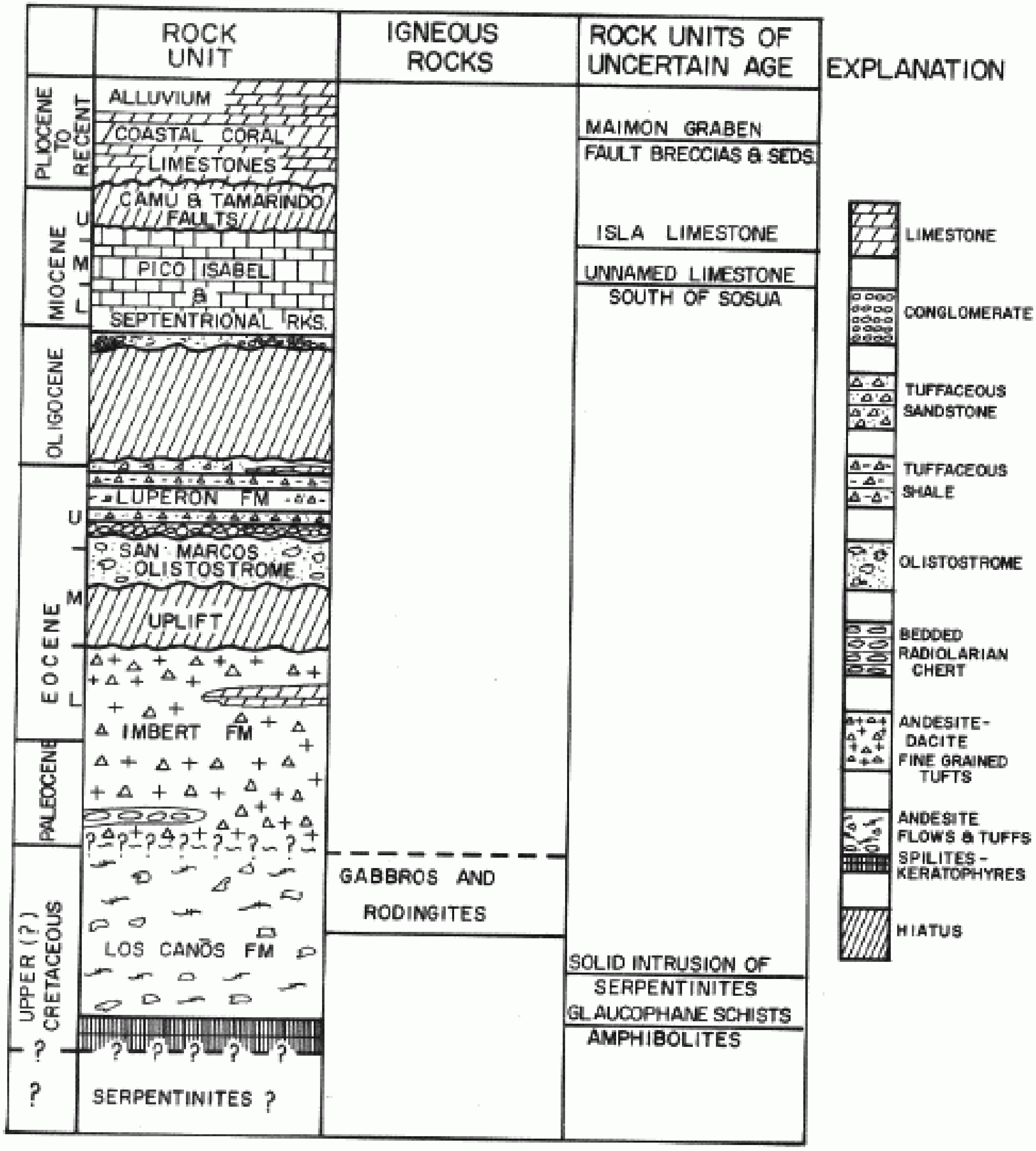


Figure 1. Stratigraphic sequence for the Puerto Plata area.

Origin

Based on several features, each of which alone could be ascribed an origin other than marine but which, when taken together, indicate a submarine environment, the writer suggests that the origin of all the varieties of alternating tuffaceous rocks and flows of the Los Caños is submarine. The features indicating this origin are:

(1) the glassy matrix of the tuffs which show strong similarities to the matrix of definite submarine or aquagene tuffs as described by Carlisle (1963); several exhibit similar quenching, globulation and pasty flow characteristics;

(2) occurrence of spilites and keratophyres within the sequence, for which "contemporary geological opinion... favors a genesis in which water, either acquired directly from the sea during submarine eruption or from sediments prior to eruption, plays a major role in the mode of solidification of the rock" (Donnelly, 1963, p. 957);

(3) a type of alteration (chloritization and albitization) that would be expected in a marine environment;

(4) turbidity current-deposited, graded-bedded, fine-grained tuffs of probable deep-water origin occurring stratigraphically above the Los Canos;

(5) age of the Los Caños rocks, the oldest in a sequence probably deposited on the oceanic crust represented by serpentinites.

Stratigraphic and Structural Relationships

Interrelationships of the varieties of Los Caños volcanic rocks are unknown. In the field and in hand specimen, only the spilites and keratophyres can be consistently recognized and are distinct from the other varieties. Almost all outcrops of the other types are greenish-brown, fine-grained volcanics.

The lower contact of the Los Caños has not been positively identified. Consistent association of the Los Caños volcanic rocks in juxtaposition with faulted serpentine bodies, however, lends support to the idea that these serpentinites are basement and represent a surface upon which volcanics were extruded.

In the eastern portion of the mapped area the Los Caños Formation is unconformably overlain by the Middle Eocene(?) San Marcos olistostrome. There are no rocks representing the Paleocene-Lower Eocene Imbert Group in this area. Contact between the Los Caños and San Marcos is difficult to draw, since the Los Caños volcanics are severely weathered here and their weathering products look similar to the San Marcos matrix. There are no exotic blocks in the volcanics, however, as there are in the San Marcos, and this feature was used to determine the approximate contact.

IMBERT FORMATION

General Characteristics

A series of tuffaceous rocks with minor fine-grained limestones and rare green radiolarian chert is well exposed north and west of the town of Imbert and is named the Imbert Formation in this report. These tuffaceous rocks can be separated into two groups: calcareous crystal tuffs and vitric tuffs. There are no known lava flows. A particularly outstanding feature of both vitric and crystal tuffs is their uniform fragment size, almost always smaller than 0.5 mm.

Calcareous tuffs occur near the base of the known stratigraphic section and are dense, fine-grained, light gray to dark gray in color, compacted, medium- to thin-bedded rocks. On a finer scale, graded rhythmic laminae on the order of 2-3 mm are visible in hand specimen. In thin section crystal fragments, mostly plagioclase, and lithic fragments, mostly pumiceous and microlitic, make up 50% or more of the rocks; the remainder is calcite matrix. Quartz fragments make their appearance for the first time in the known section in significant amounts, and range between 10 and 15% of the total crystal fragments of these tuffs. In hand specimen these tuffaceous rocks appear similar to tuffaceous rocks of the Los Caños Formation. Tuffs of the Imbert Formation are distinctly finer-grained, graded, and less altered in the lower part of the section. Grain size in the calcareous tuff graded laminae ranges from 0.3 mm to dust. The basal layer of each graded lamina is distinctly darker in color than the remainder of the layers, due mostly to pyrite dust and partial pyrite replacement of foraminiferal tests. These basal layers are also richer in foraminiferal remains than the other laminae.

Calcareous crystal tuffs of the Imbert Formation are best exposed in the stream bed of the Los Cacaitos River, about 2 km east of Imbert and north of the old Puerto Plata-Imbert road. Pelagic foraminifera in two tuffaceous rocks from these exposures have been dated as Paleocene-Lower Eocene. This age is considered the age of the Imbert Formation in this report, although it approximates only the older portion of the formation.

There are rare vitric tuffs within this predominantly calcareous sequence along the Cacaitos River, along with very rare thin, green radiolarian cherts. A general stratigraphic segregation is evident. White and buff non-calcareous vitric tuffs in the upper portion of the formation are distinct from the denser, harder, gray, more calcareous crystal tuffs in the lower portion of the formation. Transition from calcareous to vitric tuffs is gradational.

The vitric tuffs are poorly exposed north of Imbert in an arcuate band continuing north to the coast west of the Isla River. They are neither fossiliferous nor graded but are extremely fine-grained and have the appearance of white limestones. In thin section vitric ash structure, best described as vitro-clastic, is striking. Undeformed, non-welded, concave, devitrified glass shards make up over 90% of the rocks as a rule. Crystal fragments present are invariably less than 0.1 mm and only rarely is there anything other than plagioclase and quartz. Vesicular pumice fragments and pale brown to nearly colorless glass fragments are common. These tuffs are reminiscent of the andesitic vitric tuffs of the Los Caños; however, they contain quartz, are not as severely altered to calcite and chlorite, and are finer-grained.

Limestones of the Imbert Formation

Thin-bedded (1 cm thick) limestones occur in both the calcareous and vitric tuff sections. In all cases these are dense, turbid, buff or white aphanitic marine limestones with pseudo-oolites and fragments of foraminifera. Identifiable microfossils are more commonly found with the calcareous tuffs rather than the limestones of the Imbert Formation.

Cherts of the Imbert Formation

Two beds of dark green chert are known from within the Imbert Formation. Both are about 5 cm thick and are interbedded with calcareous tuffs near the bottom of the known stratigraphic section, about 2 km northeast of Imbert. One thin section of chert showed scattered poorly preserved radiolarian(?) tests, sponge(?) spicules and tuffaceous dust in a chalcedony matrix.

Relationship of the Imbert Formation to Older and Younger Units and Origin of the Formation

The Imbert Formation lies nearly conformably on the older Los Caños Formation. Contact between these two formations is consistently poorly exposed. The Imbert is unconformably overlain by Miocene rocks south of the town of Imbert and by the Upper Eocene Luperon Formation to the west.

Based upon the uniformly fine-grained size of tuffs and limestones, the fossil content of the tuffs, and the occurrence of radiolarian cherts in the section, a deep-water marine origin is proposed for the Imbert Formation.

THE SAN MARCOS OLISTOSTROME

Introduction

One of the major problems of geologic interpretation in the Puerto Plata area is a clay unit carrying a unique collection of boulders and blocks of various sizes and lithologies. The San Marcos olistostrome was not at first recognized as a unit by the author. In the summer of 1961, Hess (personal communication) suggested that this chaos was an allochthonous unit and that the blocks were exotic. In the following months, field work indicated this to be so.

The term 'olistostrome' was first proposed by Flores (1955, p. 122) for "...sedimentary deposits occurring within normal geological sequences that are sufficiently continuous to be mappable, and that are characterized by lithologically and/or petrographically heterogeneous materials, more or less intimately admixed, that were accumulated as a semi-fluid body." Rigo de Righi and Cortesini (1964, p. 1921) add that "the term olistostrome..., or 'slide accumulation,' indicates a gravity slide emplaced in a sedimentary basin and conformably overlying a marine sequence."

The San Marcos olistostrome is interpreted as a chaotic submarine gravity slide containing blocks with ages older, contemporaneous and possibly younger than that of the unindurated clay-size matrix, the whole mass of which was emplaced essentially instantaneously in a marine basin. Since this olistostrome is a lithologically distinct, mappable unit and a persistent stratum, it is also referred to in this report as a formation.

Hummocky, mounded topographic expression of the blocks within the San Marcos is a particularly outstanding feature of this formation; it is seen in the field and on aerial photographs. Wise and Bird (1964, p. 12) describe the blocks of the *argille scagliose* of the Apennines as a "chaotic littering of the landscape like so many popcorn boxes after a Saturday matinee." This analogy would also apply to the San Marcos.

Stratigraphic Position, Name, Thickness

Foraminifera from the clay matrix of the San Marcos are tentatively dated as Lower Eocene-Paleocene. The surface along which the unit slipped is unknown, but it was probably a tuffaceous horizon within the Imbert Formation. Exotic blocks within the olistostrome range in age from pre-Late Cretaceous (?) to Middle Eocene and include serpentinites and rodingites, representatives of the Los Canos and Imbert Formations, as well as rocks of unknown age.

The San Marcos olistostrome is presently distributed over approximately 90 square km in the central portion of the mapped area and occupies the core of the major antiform in this area. The oldest rocks on top of the San Marcos Formation are the Upper Oligocene-Miocene rocks of Pico Isabel. This contact is visible in only one locality known to the writer, on a trail leading from the settlement of Cupey up the south side of Pico Isabel de Torres; there the contact is conformable. The bottom contact of the San Marcos olistostrome was not observed.

The name San Marcos is taken from Rio San Marcos which flows north along the west flank of Pico Isabel to Puerto Plata Harbor. Rio San Marcos and its tributaries cut through the thickest sections of the San Marcos olistostrome, and along their banks are good representative outcrops.

The San Marcos is thickest in the west (minimum thickness 300 m) and thins somewhat to the east. Exotic blocks are less abundant in the east, but there is no apparent thinning or decrease of blocks to the north or south.

Blocks, General Description

Exotic blocks within the San Marcos Formation have sharp boundaries with the finer matrix, are invariably angular, show inconsistent strikes and dips, varied lithology, and range in size from 2-3 cm to 2 km in the longest dimension. Blocks may be found on the slopes of hills or on top of hills or as boulders in valleys. Any recognizable pattern of outcrop or lithology is completely lacking. No geologic parameter is continuous or predictable from one locale to the next.

The most common rock types forming blocks of all sizes are gray tuffs and gray or buff limestones. Both are unmetamorphosed. Also fairly common are blocks of andesite; veined, fractured and recrystallized limestones; serpentinites; and rodingites (Fig. 2). Approximately 30 different rock types occurring as blocks have been recognized by the writer. Some are definitely from the Imbert and Los Caños Formations and from older rocks, whereas others cannot be matched with known formations. What few dates the blocks have yielded indicate a range of ages from Late Cretaceous to Middle Eocene.

The Olistostrome Matrix

In the summer of 1961, 50 samples of the San Marcos 'clay' matrix were collected over a distance of about 20 km along the road being built at that time, about 3 km to the south of Pico Isabel (Fig. 3). They represent the freshest samples of the matrix known in the area. The clay is unconsolidated, gray to white in color, sometimes streaked with red hematite, and lacks bedding or directional fractures, except for occasional swirling of layers in the immediate vicinity of a block. The ratio of matrix to exotic block varies from about 1:1 to 5:1; apparently nowhere is the volume of blocks greater than that of the matrix. Since there is no bedding or marker horizon in the San Marcos matrix, it is impossible to determine what part of the section was sampled, only that samples in the west were collected from higher topographic levels than those in the east.

Figure 2. Exotic blocks of volcanic rocks in the San Marcos olistostrome, west of Puerto Plata.

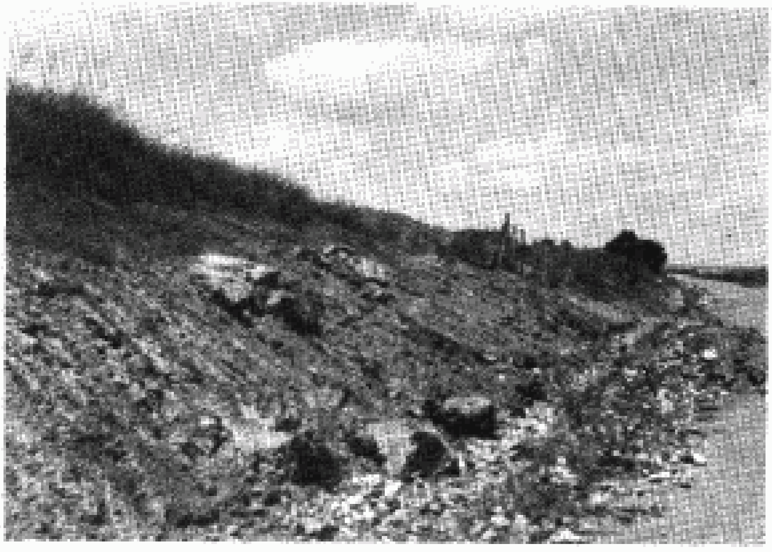


Figure 3. Clay matrix of the San Marcos olistostrome. Larger blocks are gray tuffaceous sandstones. About 4 km west of Carretera Luperon on the road to Cupey.

X-ray diffraction traces indicate that the San Marcos matrix is composed of a mixture of quartz, kaolinite, montmorillonite, chlorite, and illite. Foraminifera and radiolarians collected from the matrix were examined by Bermudez (personal communication, 1961), who identified only members of the pelagic foraminifera, *Globigerina* and *Globorotalia*. In his opinion the fauna represents a marine, deep-water environment and is of probable Lower Eocene-Paleocene age, although he notes that the collection "is insufficient to determine the age."

Origin of the San Marcos Olistostrome

Some mechanism of subaequeous gravity sliding is the most probable means to explain the chaotic San Marcos unit. There is no independent evidence for a mud diapir, salt diapir, mud volcanism or other type of activity that might lead to this type of deposit. In reference to the latter two possibilities, there is no salt and no typical fault pattern usually associated with doming; the blocks are larger than any described products of mud volcanism or mud diapirs, and most significantly, there are blocks carried along in the San Marcos matrix which are older than the matrix. This last feature does not seem to be characteristic of mud volcanoes or mud diapirs.

The very few dates from the San Marcos matrix are tentatively accepted as indicating the time of deposition of the original unit, which later became the matrix of the olistostrome. These dates give an age of Paleocene-Eocene, equivalent in age to that of the Imbert tuffaceous deposition. It is postulated that the original nature of the matrix was tuffaceous, and that it actually was a member of the Imbert Formation which was rapidly deposited while maintaining a high water content as other units buried it. The important feature of this unit is the fact that it must have maintained a rather large volume of trapped pore water during and after burial.

Spontaneous liquifaction due to shock (earthquake?) may have triggered movement of the San Marcos matrix sometime during the Middle Eocene, causing turbulent flow, destruction of original stratification, and mass movement toward a marine basin where Middle Eocene deposition was in process. Blocks were incorporated as more competent younger layers of the Imbert Formation ruptured and were swept into the moving mass. Older blocks from the Imbert Formation, the Los Caños Formation, and the serpentinites were torn loose from a submarine slope where they had formed promontories in the basement. Most perplexing is the fact that there are no Middle Eocene sediments now on top of the olistostrome. Either these sediments were removed by the Isabel slump block or later faulting and erosion, or there was simply no post-San Marcos, Middle Eocene deposition.

The base of the olistostrome has not been observed. The nature and age of the rocks underlying the olistostrome are the most critical bits of evidence now lacking.

The most likely source of the olistostrome is a few km to the west in the Imbert area, since it is here that the peridotites, Los Caños Formation and the Imbert Formation are exposed. The San Marcos itself does show an apparent decrease of contained blocks to the east and an apparent thinning to the east, also indicating a westward source.

LUPERON FORMATION

Introduction

In the northwestern portion of the mapped area there is a sequence of unmetamorphosed sedimentary rocks, herein called the Luperon Formation. The formation is named for the town of Luperon, the nearest major town to good exposures of partial section which crop out to the east of Luperon on the coastal road between Luperon and Maimon Bay. Parts of the basal members are well exposed south and west of the breccia peridotite body at La Isla and can be reached by foot traverse.

The Luperon Formation is a thick (about 1 km) repetitious sequence of poorly indurated buff and yellow-orange calcareous tuffaceous shales, bioclastic buff limestones, and calcareous tuffaceous sandstones. Generally thick-bedded calcareous sandstones alternate with thin-bedded shales and rare limestones. The beds are graded, both on the scale of the internal structure of individual beds and on a larger scale of several beds in sequence as seen in any one outcrop. Thick-bedded conglomerates form the base of the formation.

The Luperon overlies the Imbert Formation with angular unconformity. Basal units were observed in only two places southwest of Isla, and in both cases they are very thick-bedded conglomerates containing rounded pebbles and boulders of volcanic rocks, similar in texture and composition to rocks of the Los Caños and Imbert Formations. Other than the Imbert Formation, the only rock with which the Luperon is in contact is a serpentinite breccia, and this is a fault contact. Presumably, erosion has removed some of the top portion of the formation.

The Luperon Formation is exposed at the gently plunging nose of the major antiformal structure of the Puerto Plata area (Plate I). Characteristically, it shows gentle dips; outcrops often show horizontal bedding. Since the bedding is essentially horizontal, the western exposures of the Luperon Formation at higher elevations must be stratigraphically above Luperon exposures in the east.

Field Characteristics of the Basal Conglomerates

Conglomerates near the lowest exposed portions of the Luperon Formation were observed in two localities southwest of Isla. There are no exposures of conglomerates on the Luperon-Maimon Bay road. The conglomerates are very thick (1-3 m) but poorly bedded and sorted internally. The matrix is light gray to buff in color, consisting of medium to coarse, slightly calcareous quartzose sand, and is so friable as to make collection in hand sample impossible. Since outcrops are discontinuous, it was not possible to trace any conglomerate bed for distances in excess of 100 m.

The larger clasts in the conglomerates are predominantly fine-grained gray limestones of unknown age and origin. Their size ranges from nearly 1 m down to several cm, the larger sizes being subangular. The known limestones of the Imbert Formation are rare and very thin-bedded, yet the Imbert Formation is the most likely source of these clasts.

Other rock types forming clasts, usually well rounded in the pebble- and cobble-size range, are volcanic rocks. Several of these were studied in thin section, and the writer is fairly confident in stating that there are rocks of both the Los Caños and Imbert Formations among them. Also noted as clasts were cherts, gabbros (thus, at least some gabbros are pre-Upper Eocene) and two well rounded coarse pebbles of quartz diorite. There are no known quartz diorite bodies in the mapped area. The nearest such diorites (tonalites) are approximately 70 km away, across the Cordillera Septentrional and Cibao Valley in the area mapped by Palmer (this volume). Inspite of the fact that the predominantly Miocene Cordillera Septentrional would not have been a topographic barrier during Middle and Late Eocene time, the tonalites 70 km southwest seem to be an unlikely (but not impossible) source for these rounded hand-sized pebbles. Alternative sources might be an undiscovered body within the interior of the area mapped as Los Caños, or an unknown source in the relatively unmapped Septentrional to the south.

Bioclastic Limestones

Occasional thin to medium beds of dense gray fossiliferous limestones occur in the generally tuffaceous sandstone-tuffaceous shale sequence, usually above the shale and under the sandstone. A typical example was collected about 8 km southeast of Luperon. In thin section this rock proved to be composed nearly entirely of cryptocrystalline calcite with rare quartz grains and contains both fragments and whole remains of organisms. Cole (personal communication, 1960) identified the benthonic foraminifera *Asterocyclina minima* and *Lepidocyclina macdonaldi* and stated that the assemblage is definitely Upper Eocene.

Tuffaceous Sandstones

Tuffaceous sandstones are the most abundant rock type of the Luperon Formation, forming the thickest (30 cm) beds in the repetitious sandstone-shale sequence. Thickness of these beds is quite constant from one repetition to the next in a vertical sequence (ranging from 10-30 cm). Thickness is also constant from one outcrop to the next over distances of 20 km. Since outcrops are discontinuous and appearances of the sandstone in hand specimen and thin section are not distinctive, however, correlating any one particular sandstone bed for such distances will require additional detailed work.

Four well cemented hand specimens were collected and sectioned. All of them contain foraminiferal fragments and three were dated as Upper Eocene by Cole (personal communication, 1960) and Bermudez (personal communication, 1961).

Tuffaceous Shales

Fine-grained buff and orange-brown tuffaceous shales and siltstones form the second most abundant rock type of the Luperon Formation and occur as thin- to medium-bedded rocks alternating with the tuffaceous sandstones. Two samples are fossiliferous and were dated by Bermudez (personal communication, 1961) as probable Upper Eocene.

Environment of Deposition and Origin

There is conflicting evidence concerning both source area for some of the Luperon clastic material and depositional environment of the clasts. In the writer's opinion, all rock types are epiclastic. There is little, if any, primary pyroclastic material. Basal conglomerate members contain clasts of volcanic and cherty rocks which appear to be weathered from the Los Caños and Imbert Formations. The rather abundant and sometimes surprisingly large clasts of fine-grained limestone could represent an unknown member of the Imbert Formation, but more likely they are intraformational in origin. The source for the two quartz diorite pebbles is unkonwn.

The tuffaceous sandstones, siltstones and shales which dominate the Luperon Formation have a high quartz content, most grains of which are somewhat rounded and apparently reworked. Some of this quartz could have come from tuffs in the Imbert Formation or keratophyres from the Los Caños Formation; in no known case, however, does a rock from either of these formations contain more than 15% quartz. Perhaps this is further evidence for an undiscovered quartz diorite intrusive. Bermudez (personal communication, 1961) has commented that the fauna from the tuffaceous sandstones indicates a shallow marine environment, whereas that from the tuffaceous shales indicates a marine deep-water environment. These two rock types alternate throughout the sequence. The rare bioclastic limestones with their neritic fauna are also apparently of shallow-water marine origin. The poorly sorted, massively bedded basal conglomerates probably formed in a near-shore shallow-water marine environment.

There are no known Middle Eocene rocks *in situ* in the Puerto Plata area. This time period was probably one of weathering and erosion of the uplifted Early Eocene and older rocks. During the Upper Eocene, deposition began again. The shallow portion of the sedimentary basin was located to the south and east, where conglomerates, together with thick-bedded sandstones and the single dated bioclastic limestone, are presently found. The writer suggests that there were deeper portions of the basin to the north and west, where turbidity currents might have created the rapidly alternating graded sequences leading to apparently contradictory evidence concerning depth of deposition.

Age of the Luperon Formation

Five samples of rocks from the Luperon Formation were dated by Bermudez (personal communication, 1961) and Cole (personal communication, 1960) as Upper Eocene. These samples are all from western exposures of the formation and represent the age of the middle or upper portions of the unit but do not necessarily represent the age of the basal unit. The Luperon rests with angular unconformity on the Imbert Formation, which has been dated as Paleocene to Lower Eocene. The writer accepts, therefore, an age of Upper Eocene for the Luperon Formation.

OLIGOCENE(?)-MIOCENE ROCKS OF PICO de ISABEL de TORRES AND THE CORDILLERA SEPTENTRIONAL

Introduction

In the central portion of the mapped area, white, buff, and gray fossiliferous limestones form the highest peak in the Puerto Plata area, Pico de Isabel de Torres, which rises 800 m above sea level. Focus of the present study was on the age range of the rocks exposed on Pico Isabel, the contact relationships between these rocks and the San Marcos olistostrome, and the age relationships of the Pico Isabel section to the Tertiary rocks of the Cordillera Septentrional.

Pico de Isabel de Torres

Rock units which form Pico de Isabel de Torres are covered by alluvium on the north, east, and west flanks and are interpreted to be in fault contact with the San Marcos olistostrome to the south. An attempt to traverse the north slope was unsuccessful. The best partial section could be reached in 1960 from the south following an unsurfaced road north of Cupey to the mountain peak. Exposed rocks are well consolidated, porous, white, buff, and gray limestones which vary from medium- to very thick-bedded. All the limestones contained megafossils (corals and molluscs) and/or microfossils, although only the microfossils were examined by paleontologists. The only other rock type seen is at the base of this section and is only partly exposed. A fine-grained, greatly sheared and weathered, non-fossiliferous shale, it is considered by the writer to be one of the probable units along which gravity sliding took place, thus moving the Pico Isabel section from a former, more southern location in the Septentrional to its present position.

The limestones show northern dips near the base of this partial section but southern dips at the top of the peak, indicating a more complicated structure than that shown on Plate I. Since only gentle folding is indicated, faulting may be more complex than noted.

The entire sequence of limestones from the basal unit to the topmost bed, an estimated 500 m-thick section, has been dated as Miocene. Two older dates, both Oligocene, have been reported from other localities on Pico Isabel, one on the northern flank 300 m above sea level (Vaughan *et al.*, 1921, p. 123) and another on the eastern flank 4 km southeast of Puerto Plata on Carretera Luperon (Bermudez, 1949).

Tertiary Rocks of the Cordillera Septentrional and Southwest of Sosua

The basal(?) units of the northern flank of the Cordillera Septentrional were observed in several localities between Imbert and Carretera Luperon south of the Camu River. In most cases the rocks exposed are isolated blocks of medium-bedded limestones dipping steeply to the south. The writer interprets these as rotated blocks in the fault zone, which extends for most of the distance parallel to and immediately south of the southern bank of the Camu River. Limestones forming one of these fault blocks 2 km east of Imbert have been dated as Miocene. A conglomerate of probable Miocene age rests unconformably on the Imbert Formation 3 km east of Imbert and probably represents the general relationship of the Miocene rocks to the older formations prior to faulting and gravity sliding. Lens-like conglomerates of unknown age are also present at the base of the Tertiary sequence exposed along Carretera Luperon and are noteworthy in that interbedded siltstones contain plant remains, although not well enough preserved for identification. Limestones several hundred meters higher in the Septentrional section along the same road have yielded Miocene dates.

A massive, gently northward-dipping plate of limestone about 50 m thick crops out south and west of Sosua. Since the outcrop pattern of this unit is not known, the unit was not differentiated on Plate I from the Septentrional sequence. Most likely, the Middle Miocene date reported by Bermudez (1949) from a well in limestone in Sosua came from this unit. Earlier in this report, the writer suggested a possible correlation to similar massive limestones observed only from a distance at higher elevations in the Septentrional south of Sosua. These limestones lie unconformably on the known Miocene section of limestones and shales.

ISLA LIMESTONE

In the north-central portion of the map area, there is a belt of low-lying, discontinuous, irregularly-shaped limestone blocks aligned approximately northwest-southeast 10 km east and west of Maimon Bay. The blocks occur in a narrow zone about 2 km north-south and lie unconformably on the Los Caños Formation on Loma la Bestia, the San Marcos olistostrome, and a breccia-serpentinite body west of Maimon Bay. The name for the limestone is taken from the small settlement of La Isla west of Maimon Bay.

The limestone is a dense, gray to white, aphanitic, massive rock. Brecciated and recemented everywhere, it is unstratified and breaks with a conchoidal fracture. Prominent vertical joints give outcrops a blocky aspect, and the massive white castellate blocks are an eye-catching feature of the Maimon Bay area. Thickness of this limestone varies from 5 to 20 m. There are no overlying rocks in contact with these blocks, except in one case east of Maimon Bay, where a block rests in alluvium. Most of the blocks are found between 200 and 300 m above sea level, although two blocks east of Maimon Bay and north of the coastal road lie at approximately 50 m of elevation.

Twenty-five thin sections of this limestone were studied. The brecciated and recemented texture and the rich microscopic organic debris in chaotic distribution make this limestone petrographically distinct from all others in the Puerto Plata area. The mineralogy is monotonous from one slide to the next, consisting of cryptocrystalline dusty calcite in the breccia fragments, with clear calcite rhombs filling veins and cracks surrounding the fragments.

Seven of the thin sections, cut from basal portions of the limestone blocks resting on serpentinite breccia west of Maimon Bay, contain angular and rounded fragments of serpentinite. Some of the serpentinite fragments show weathered rims; in no case can this be misconstrued as serpentinite intruding limestone, since the calcite matrix adjacent to the serpentine fragments is entirely unaltered. Occasional veins containing serpentine dust and calcite are present in these samples. The writer was not successful in obtaining material suitable for thin sections from the basal portion of the blocks on Loma la Bestia, where weathered fragments of probable Los Caños were observed to be incorporated into the breccia.

Origin and Depositional Environment

The Isla Limestone bears strong similarities in appearance, outcrop distribution, and internal structure to the *morros* of San Juan in central Venezuela described by Shagam (1960), Kugler (1953) and Caudri (1944). Shagam considers the *morros* to be reef-type limestones; Caudri has interpreted them as upturned limestones, and Kugler as large slump blocks.

The writer considers the Isla Limestone to be an originally discontinuous shallow-water marine limestone of probable reef type. The brecciated and recemented rock, containing fragments of algae, foraminifera and other organic remains, suggests the presence of organisms capable of binding organic debris into a rigid structure. Somewhat complicating this idea is the general lack of surrounding sedimentary rocks or evidence of reef debris, facies normally associated with reefs. Perhaps these were bioherms too small to develop the associated facies. As mentioned, none of the outcrops is bedded; thus, the only apparent alternative, aside from bioherm development, is that of slump blocks. The writer's major objections to this formational process for the Isla Limestone are that nowhere is there a likely source for these blocks and that the blocks are restricted within the map area to a relatively narrow strip. The relationship of these small blocks of Isla Limestone to the probable Middle Miocene massive limestone 20 km to the east and southwest of Sosua is unknown.

Age of the Isla Limestone

Numerous thin sections of Isla Limestone hand samples were made in an attempt to find suitable organic material for a paleontologic date. The attempt was unsuccessful. Bermudez (personal communication, 1961) reports Miliolidae, calcareous algae, and unidentified foraminiferal fragments. Concerning ecology of the fauna, Bermudez states that it probably represents a shallow-water marine assemblage.

The Isla Limestone rests unconformably on the Los Caños Formation (pre-Paleocene), serpentinite breccia (unknown age) and the San Marcos olistostrome (probably Middle Eocene). Thus, little can be said concerning the age of the Isla Formation, except that it is post-Middle Eocene. The writer guesses that it is Miocene or younger.

POST-MIOCENE UNITS

Three post-Miocene units were recognized in the map area and appear on Plate I, but little time was devoted to their study. The three units are: (1) coastal reef limestones; (2) fault breccias and alluvial sediments associated with the Maimon graben; and (3) stream alluvium.

SERPENTINITES

Field Occurrence

Irregular linear outcrops of serpentinite are common both east and west of Maimon Bay (northern part of the mapped area) and east of Imbert (southern portion of the mapped area). Exotic blocks of serpentinite up to 2 km in length occur within the San Marcos olistostrome. The Maimon Bay and Imbert outcrops are in fault contact with the Los Caños, Imbert, and Luperon Formations. None shows evidence of magmatic emplacement.

In common association with serpentinites throughout the mapped area are gabbros or altered gabbros converted to rodingite near the margins of the serpentinites. The gabbros are intrusive into both the Los Canos volcanic rocks and the peridotites, thus are younger than both. The association of serpentinite, gabbro (rodingite) and rocks of the Los Canos Formation extends to some of the larger exotic blocks in the San Marcos olistostrome.

In the field two textural types of serpentinites can be recognized. The first, termed massive serpentinite, is characterized by a blocky appearance, greatly fractured and sheared. Predominantly black to greenish-black in color, these serpentinites commonly show smooth surfaces of apple-green serpentine. The only identifiable original mineral in hand specimen is the orthopyroxene enstatite, although it is usually altered to bastite. Massive serpentinites are exposed for some 4 km along the north coast immediately east of Maimon Bay, also in several smaller individual bodies east of Imbert, and as exotic blocks in the San Marcos olistostrome.

The second textural type is serpentinite breccia. This variety is characterized by dark green to black serpentinite fragments varying from microscopic size to cobbles in excess of 1 m (Figs. 4A, B, C) set in a lighter green serpentine matrix. The largest serpentinite body in the mapped area, in the vicinity of La Isla west of Maimon Bay, is of the breccia type and measures about 4 km north-south by 2.5 km east-west. Other smaller serpentinite breccia bodies occur as distinct units east of Imbert and as blocks in the San Marcos olistostrome.

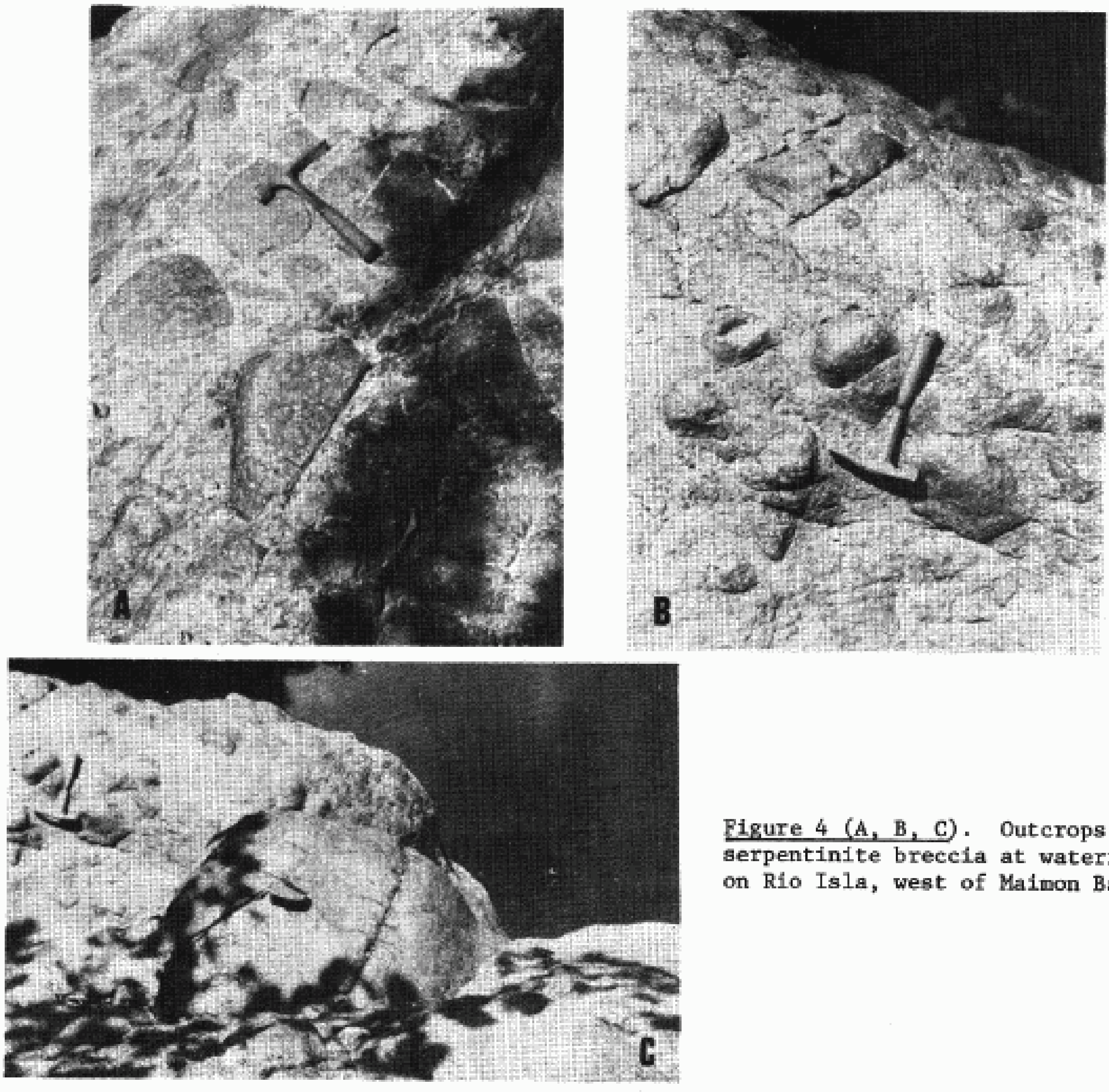


Figure 4 (A, B, C). Outcrops of serpentinite breccia at waterfall on Rio Isla, west of Maimon Bay.

Petrography of the Serpentinites

Serpentine Minerals and Textures

The serpentinites, whether of the massive or breccia type, are made up of 90-100% serpentine minerals. One can recognize thorn or flame textures typical of antigorite in both types, and antigorite has been positively identified in the only breccia sample x-rayed. The thorn texture serpentine is the most common constituent of both fragments and matrix of the serpentine breccias. The serpentine texture of the massive serpentinite is much more variable. Most abundant is mesh texture serpentine (chrysotile?), pseudomorphic after olivine, but also common are bastite pseudomorphs after enstatite, and fragments and minute veinlets of chrysotile. X-ray diffraction patterns of two massive serpentinites indicated a mixture of serpentine minerals with lizardite predominant.

At one locality about 2 km southwest of Puerto La Isla along the Isla River at the lip of a 20-m waterfall, limestone fragments occur in the breccia. The fragments are angular, irregularly shaped, range in size from 2-10 cm in longest dimension, and are probably of the Isla Limestone of unknown age, which rests unconformably on the breccias in patchy distribution in several localities within 100 m of this outcrop. It is perhaps pertinent that all samples of the breccia matrix which contain secondary calcite also come from this waterfall outcrop. The limestone fragments are the only breccia fragments known that are not serpentinites or peridotites and were seen only at this locality.

Sectioning pebble- and cobble-size fragments of the breccia, collected approximately 4 km south of Puerto La Isla in the central portion of the southern lobe of this body, revealed that the interiors of several fragments (12-15 cm in diameter) are not serpentinized but are composed typically of 85% olivine, 10% enstatite and 5% spinel. The outer 2-3 cm appear similar to fragments elsewhere and are serpentinized.

Breccia matrix in this area is extremely sheared. The only noted case of a severely sheared matrix in the serpentinite breccias, it is also one of the few areas in which matrix material is more abundant than fragments.

Inclusions in the Serpentinites

In addition to the limestones described above, inclusions within serpentinites can be conveniently divided into three groups. One, altered diorite, is represented by only one known occurrence and will be discussed with the more abundant second group, rodingites, in a later section on rodingites, diorites and gabbros. Both of these types are intimately associated with gabbroic igneous intrusions and involve an origin which is considered distinctly different from the origin of the third group: blocks of actinolite schist, glaucophane schist, and marble.

Serpentinites east of the town of Imbert contain large blocks of actinolite schist, glaucophane schist, and black marble which were found nowhere else in the Puerto Plata area. The blocks are large (several in excess of 30 m by 10 m) and rest in a haphazard manner on the surface of the serpentinites. In no case was one of these blocks found to be completely surrounded by serpentinite, and their present apparent random distribution does not represent a definable contact metamorphic zone of the serpentinites. Three or four smaller blocks lie near serpentinites on the surface of weathered Los Caños rocks. The fact that there are no other blocks diluting this rather distinct assemblage and that there is no clay-like matrix evident makes it unlikely that these blocks represent a portion of the San Marcos olistostrome.

Origin of Tectonic(?) Inclusions

Inspite of the extremely limited samples of inclusions observed and the uncertainty as to their significance, one is tempted to speculate about their origin. The writer suggests that these rocks represent a small slice of regionally metamorphosed basement, perhaps altered Los Caños, brought to the surface along fault surfaces together with relatively cold, solid serpentinites which represent hydrated mantle. Microscopic investigation suggests a progressive mineralogical change in rock types from hornblende-andesite-tuff - to - glaucophane schist - to - actinolite schist.

The writer favors the interpretation of rapid burial of the lower units of the Los Caños Formation by succeeding members of the Los Caños and Imbert Formations in a submarine environment of low geothermal gradient, perhaps an oceanic trench, the trench itself floored by serpentinite. The only likely place in an island arc setting to produce glaucophane is in a low heat flow area, such as an associated trench. It is perhaps not entirely coincidental that one can plot a line through Puerto Plata, Gaspar Hernandez and Sanchez, linking a discontinuous linear belt of serpentinites and associated metamorphic tectonic inclusions.

Origin and Age of the Serpentinites

The present crustal environment and attitude of the Puerto Plata serpentinites seems unrelated to their initial mode of origin. What does seem significant is that the serpentinites are situated near to, or occur in, the Los Caños Formation, the oldest recognized formation of the area, and that this formation and the serpentinites form the core of the major antiformal structure that dominates the Puerto Plata area. Mattson (1960) and Hess (1960) suggested that a similar structural setting for the Bermeja complex in Puerto Rico could be interpreted as basement (oceanic crust) brought to the surface in the process of deformation. Both authors mention a similar tectonic setting for serpentinite occurrences in eastern Cuba (described by Thayer and Guild, 1947).

For 10 or more years Hess developed and refined the idea of serpentinite as the major constituent of the oceanic crust on the basis of geologic and geophysical evidence (see in particular Hess, 1954, 1955, 1959, 1962, 1964). Occurrences of serpentinite in the Puerto Plata area, Dominican Republic, eastern Cuba, and southwestern Puerto Rico lend support to Hess' general thesis in the area of the Greater Antilles. Dredging of serpentinite from the north wall of the Puerto Rico Trench (Bowin and Nalwalk, 1963; Bowin *et al.*, 1966), as well as from fault scarps on the Mid-Atlantic Ridge (Shand, 1949), is also strong direct evidence for at least some serpentinite in the oceanic crust.

The writer believes that the discordant intrusive serpentinites of the Puerto Plata area were relatively cool intrusions representing detached upper mantle slivers and that they were emplaced essentially as solid bodies. The mechanism of cold intrusion has been generally thought to be that of plastic deformation of serpentinite, since serpentinite is an especially weak rock.

Raleigh and Paterson (1965) review the situation and present data on the strength and behavior of serpentinite at temperatures up to 700°C and confining pressures up to 5 kb. "The striking feature of the serpentinite experiments with sealed specimens is the sharp transition from ductile to brittle behavior that occurs upon increase of temperature even at the relatively high confining pressure of 5 kb" (Raleigh and Paterson, 1965, p. 3977). The mode of failure is brittle fracture, not general plastic deformation, and brittle fracture as well as subsequent sliding on fracture surfaces (solid intrusion) are possible in serpentinite at low shear stresses only if appreciable water pressure is in equilibrium with its mineral assemblage. Raleigh and Paterson (1965) suggest partial dehydration of the serpentinite at temperatures of 300 to 600°C, depending upon composition and total pressure, the water pressure not exceeding total pressure, hence not being lost in appreciable amounts to surrounding rocks.

Observed behavior of serpentinite under the experimental conditions imposed by Raleigh and Patterson provides an explanation for the two textural types of serpentinite bodies in the Puerto Plata area. The two occur as individual bodies in the same geologic and structural setting, implying a common origin. The writer concludes, with support from the findings of Raleigh and Paterson, that the two textural types are a reflection of differences in strength, the massive sheared serpentinites representing somewhat more ductile behavior than the breccia bodies, which perhaps suffered greater dehydration, thus inducing a more brittle behavior. Fresh fractured olivine occurring west of Maimon Bay in large quantities in breccia cobbles seems to support this idea. Ultimately, this strength difference may have been brought about by small temperature gradients which, according to Raleigh and Paterson (1965, p. 3982), may "produce large gradients in water pressure and, consequently, large gradients in strength."

It is of interest that Raleigh and Paterson suggest that their model might be appropriate to explain the serpentinite breccias of Queensland described by Wilkinson (1953). There is little doubt that the serpentinite breccias from Puerto Plata show striking similarities to those from Queensland, both in hand specimen and thin section. This similarity was confirmed by Wilkinson (personal communication, 1959) upon direct observation of hand specimens from Puerto Plata.

Green (1961) described 5 types of ultramafic breccias from eastern Papua on the basis of petrography: mesh texture serpentine breccia, antigorite serpentine breccia, peridotite breccia, gabbro breccia, and basalt peridotite breccia. The Papuan breccias show two modes of occurrence: (1) irregular and non-linear transgressive breccias and (2) conformable sheet breccias. Detailed field and petrographic observation, plus several chemical analyses on the matrix of the breccias (Green, 1961), rather convincingly support the contention for the close association of breccia origin and volcanic activity. "The breccias are interpreted as vent and extrusive breccias resulting from the penetration, brecciation, and local entrainment (fluidization) of peridotitic country rock by volcanic gasses. Olivine alkali basalt was probably the parental magma responsible for the gaseous activity" (Green, 1961, p. 1).

Serpentinite breccias of Puerto Plata do not show such intimate involvement of basalt and unaltered peridotite and gabbro. Neither are there any conformable sheet-like bodies here. Minerals (chalcedony, magnesite, quartz, andradite) which Green considers as having recrystallized in the matrix due to additions of SiO_2, CO_2, Al_2O_3, and O_2 from volcanic gasses are not present in the Puerto Plata serpentinite breccias. Brecciation by "fluidization" seems an unlikely explanation for breccia origin in the present case.

There are several other possible mechanisms for producing breccias, all of which are considered doubtful in the Puerto Plata area. Fault breccias seem reasonable; however, all the serpentinites occur along faults, and only a few are brecciated. Also, the matrix of the breccia is usually not sheared, and when it is, the shearing intensity is not related to the location of a fault. A sedimentary origin for all the breccias is inconsistent with the lack of admixed material and lack of bedding. The limestone clasts within the breccias in the waterfall locality mentioned earlier might be a local example of sedimentary origin. If talus brecciation is involved, one would expect to find a likely nearby source, some clast component other than serpentine, and some noticeable size gradation. None of these conditions was observed.

Hess (1962, p. 612-613) suggested that oceanic crust and mantle might fracture and dilate under oceanic ridge crests (thus explaining the abnormally low seismic velocities there), since presumably this would be the region where convective flow changes from vertical to horizontal. As convection continued, these fractured areas would be carried to the ridge flanks where they would reheal "by slight recrystallization or by deposition from solutions." Perhaps then one should expect to find some brecciated serpentinites among the fragments of detached mantle. If this were the mechanism of origin, one would expect these breccias to be much more common, particularly in island arcs which most likely are built on oceanic crust. The writer knows of no other examples of breccias of this type described from existing island arcs.

The serpentinites in the mapped area are considered to be the oldest rocks exposed, in fact, the oceanic floor upon which rests the entire stratigraphic column. Most serpentinite bodies were probably emplaced at their present stratigraphic level along faults of pre-Imbert Formation age and thus are pre-Paleocene, post-Late Cretaceous. At least one serpentinite breccia body was emplaced or continued to move upward in post-Late Eocene time and is in fault contact with the Luperon Formation.

GABBROS, RODINGITES AND DIORITES

Lenticular and stock-like bodies and dikes of gabbro, altered gabbro, and diorite occur as fault-bounded 'intrusives' in the serpentinites and Los Caños Formation in the Puerto Plata region. The only true intrusive contacts found, however, involve small dikes of rodingite in serpentinite (Fig. 5). The majority of the remaining igneous bodies are found as: (1) dikes at the sheared contacts of serpentinites and Los Caños volcanic rocks; (2) stocks of gabbro and altered gabbro in either serpentinite or the Los Caños with fault contacts; (3) minor gabbro-troctolite-serpentinite complexes; (4) allochthonous blocks along with serpentinite in the San Marcos olistostrome.

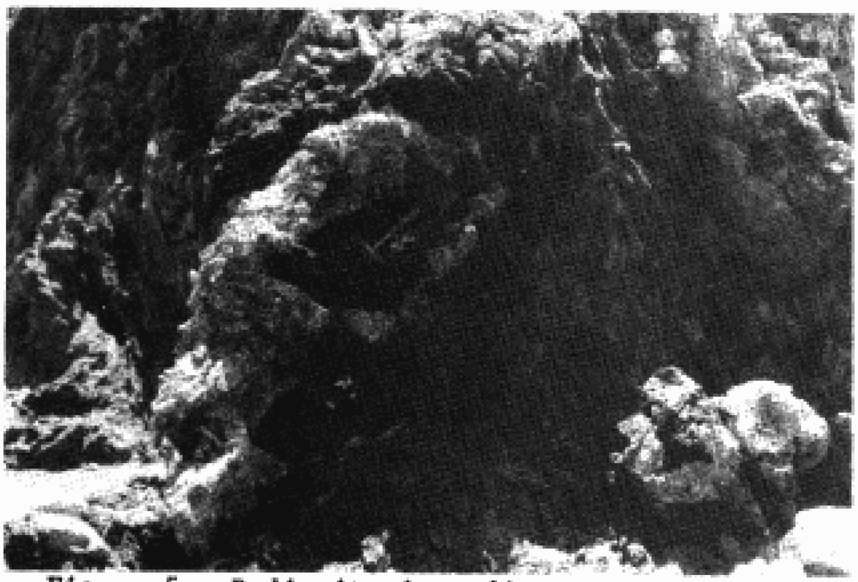


Figure 5. Rodingite intruding serpentinite. Atlantic coast, about 3 km east of Maimon Bay.

Ware (1962) studied the rodingites and related rocks found in the Puerto Plata area east of Maimon Bay, west of Puerto Plata, and east of Imbert. He concluded that all rocks originally consisted of pyroxene and plagioclase, and in a few cases olivine, pyroxene and plagioclase, although most have since undergone alteration to varying degrees. Ware found that the rocks could be classified as gabbros (including troctolites), altered gabbros, tremolite-rich rocks and rodingites. The term 'rodingite' is employed by Ware (1962) and in this report to refer to an altered rock with appreciable grossularite or hydrogrossularite garnet. The writer is not familiar with the exact location of Ware's tremolite-rich rocks, but they apparently are two small unique dikes in serpentinite from the Imbert area. They may very well be altered microdiorite.

Origin and Age of Gabbros, Altered Gabbros and Rodingites

There are several known occurrences of gradation from gabbro to altered gabbro to rodingite within dikes and faulted stocks as the serpentinite country rock is approached. There are no known rodingite dikes which are far from serpentinites or which intrude volcanic rocks. Some rodingites do occupy sheared contacts between serpentinite and volcanic rocks of the Los Caños (Fig. 6).

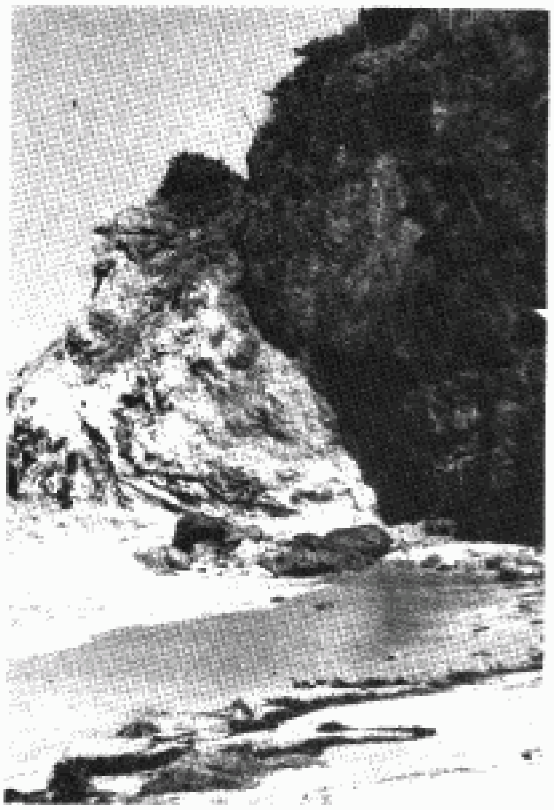


Figure 6. Altered gabbro and rodingite complex in fault contact with Los Caños Formation. Atlantic coast, about 2 km east of Maimon Bay.

De (1960, p. 179) stated that most authors have attributed formation of this rock to the metasomatic alteration of mafic dikes by lime-rich solutions released by serpentinization of a clinopyroxene-bearing ultramafic rock. As a result of his own work in Quebec, however, De (1960, p. 185) concludes that rodingites form by the crystallization of gabbros or diorites in the water-rich and silica-deficient environment of serpentinized ultramafic rocks.

Rodingites originate in more than one way, but all are associated with serpentinites. Schlocker (1960) describes rodingite developed in a volcano-tectonic inclusion in serpentinite. Chesterman (1960) describes rodingite developed at a serpentinite-graywacke contact and Challis (1965) at a serpentinite-amphibolite contact.

As suggested by Ware (1962, p. 44), the gradational sequence mentioned, the indication of magmatic temperatures within the center of gabbroic dikes, and lower temperatures (700°C) near the serpentinite contacts seem to fit best the mechanism suggested by De and agree with his general picture (De, 1960, p. 188) of a continuous process of crystallization from magmatic to hydrothermal conditions. The gabbros and rodingites, then, are tentatively considered to be older than the Imbert Formation (Paleocene-Eocene) but younger than the Los Caños Formation (Upper Cretaceous or older).

STRUCTURE

There is only a minimum of data to control structural interpretation of the Puerto Plata area. Strike and dip information on the Los Caños Formation is sparse, due primarily to the generally massive structure of individual units and deep weathering of the entire formation.

The dominant structural feature is a broad intensely faulted antiform, which trends about N 55°W parallel to the north coast of the Dominican Republic and plunges to the northwest. This antiform has apparently served as a locus for the only significant Middle Eocene episode of folding to affect the Imbert and Los Caños Formations and for mild warping during the Late Miocene. Folding is not a major mechanism of deformation within the map area.

Oligocene(?)-Miocene rocks are situated on the north, south and east flanks of the antiform, and Upper Eocene rocks are found on the northwest nose. Proceeding inward from the nose toward the core of the antiform, one first finds arcuate outcrop belts of Paleocene tuffs (Imbert Formation), then Upper(?) Cretaceous volcanic rocks (Los Caños Formation). The latter contain fault-bounded bodies of gabbro, which were emplaced prior to the Paleocene. Serpentinites are also within the Cretaceous volcanics, are intruded by gabbros, represent basement rock, and have been faulted into their present positions. The central core of the antiform is occupied by the allochthonous Middle Eocene(?) San Marcos olistostrome.

Faults

A major fault, herein named the Camu Fault, which trends approximately N 70°W and on which relative movement was predominantly vertical, extends about 30 km along the southern margin of the antiform and separates Miocene rocks from the San Marcos olistostrome, Los Caños Formation and serpentinite. There are small areas of undated sedimentary rock which may be older than Miocene at the base of the section on the upthrown side of the fault. The known fault trace extends from Imbert to 2 km east of Carretera Luperon. A probable westward extension is postulated from aerial photographs. A postulated eastward extension is much less definite, since either the fault decreases in displacement in this direction or is overlain by younger rocks, or both. The fault plane is not exposed anywhere. Regarding movement on the fault, Miocene rocks unconformably overlie the Imbert Formation in one locality near Imbert and are topographically lower than Miocene rocks immediately to the south. East of Carretera Luperon, Miocene rocks north of the fault line are also topographically lower than Miocene rocks south of the trace. These instances suggest that the Camu Fault was active in post-Miocene time and that the relative motion since that time has been north side down. Extent of this motion is unknown but is estimated to be several hundreds of meters since Miocene time.

Bowin (1960, Plate 3) indicates a fault several hundred km long separating the Cibao Valley from the southern flank of the Septentrional and showing a relative upward motion of the Septentrional. This fault truncates rocks of Upper Miocene age in the Cibao Valley, suggesting a similar time of movement there and on the Camu Fault.

On the northern flank of the antiform 10 km north of the Camu Fault, a second major fault occurs, the Tamarindo Fault, with approximately the same trend and similar relative motion as the Camu. It extends for a known distance of 4 km east of Maimon Bay and disappears under Recent alluvium. Probably the same fault or fault zone extends in the form of two faults 4 km west of Maimon Bay along the northernmost exposures of the gabbro and serpentinite breccia bodies. These two faults have the same trend, offset *en echelon* from each other and from the main fault east of Maimon Bay. Although the fault plane was not observed, existence of the fault is evidenced by a scarp expressed topographically by higher elevations to the south and geologically by abrupt termination of outcrops of serpentinite and gabbro against the Los Caños, and Luperon Formation rocks against serpentinite. As evidence that motion on this fault is correct as noted on Plate I, the Isla Limestone of probable shallow-water origin is now at elevations of 200-300 m south of the fault line trace, whereas two outcrops of Isla Limestone north of the trace are at elevations of approximately 50 m. These outcrops could be talus blocks, however. Time of motion on the fault was certainly post-Late

Eocene and probably Miocene or later, if the supposed age of the Isla Limestone is correct. The Camu and Tamarindo Faults may have been active at the same time.

Several smaller faults shown on Plate I are at the borders of serpentinite or gabbro intrusions. Apparent motion along these smaller faults is dominantly vertical, but some strike-slip motion has been postulated along a few of them to explain the outcrop pattern.

Two parallel faults about 1 km apart, parallel to and coinciding with the east and west shores of Maimon Bay, form a narrow graben extending about 8 km northeast-southwest through the central portion of the area. Maimon Bay occupies the northern end of the graben. Available bathymetric charts are not sufficiently detailed to indicate whether this feature extends into the Hispaniola Channel. The southern ends of both faults are anomalous. Outcrop pattern as mapped indicates some strike-slip motion on both, probably earlier than the formation of the graben. Yet latest relative motion, where observed in one location near each fault, appears to be vertical. The graben does not extend across the Bajabonico River into the Cordillera Septentrional. The writer contends that the Maimon graben formed after the Tamarindo Fault, sometime between the Miocene and present.

Gravity Sliding

At least two episodes of gravity sliding are recorded in geologic history of the Puerto Plata region. The San Marcos olistostrome event was the first, occurring essentially instantaneously sometime in the Late Middle Eocene. As suggested, the flow of the San Marcos was probably triggered by shock liquification of the matrix, the unit then rapidly moving down a gentle slope, incorporating blocks of contemporaneous and older rocks. Source of the material was probably to the south or to the west of its present distribution.

A second episode of downslope mass movement occurred in post-Middle Miocene time and involved the Oligocene (?)-Miocene rocks of Pico Isabel de Torres, which traveled as a unit moving over the San Marcos from south to north. Minimum amount of movement must have been 4 km, which is the present shortest distance from the flank of Pico Isabel to the Septentrional, and may have been related to activity on the Camu Fault. The writer suggests that after detachment from the main Septentrional, the Pico Isabel block repeatedly slid either on an unstable, periodically reshocked San Marcos surface or on its own unstable basal shale members, or both. Surface gradient is unknown, but if one assumed that the basal layers exposed on Pico Isabel still represent that slope, a 20^{o}N slope is estimated.

Trench Tectonics? - A Regional Problem

The writer proposes that Puerto Plata and perhaps the northeast coast of Hispaniola represent a raised portion of the southern flank of the present Puerto Rico Trench. The rock record of the map area indicates probable early submarine deposition of volcanic flows and tuffaceous rocks, as well as turbidity current deposits of tuffs and later tuffaceous sediments. This entire sequence ranges in age from probable Upper Cretaceous to Upper Eocene and was deposited on a serpentinite basement. Some of the earlier hornblende-bearing volcanics have been converted to glaucophane schists and actinolite schists in a low temperature zone at depth. Dredge hauls from the north wall of the Puerto Rico Trench have indicated a possible stratigraphy of serpentinized peridotite with altered basalt overlain by Upper Cretaceous sedimentary rocks, which are in turn overlain by Lower Tertiary sedimentary rocks with minor vitric basalt (Bowin *et al.*, 1966). This sequence is similar to the proposed stratigraphy of the Puerto Plata area.

Deeper portions of the Puerto Rico Trench are approximately 200 km east of the northeast coast of Hispaniola, but a shallower axial portion of the trench apparently continues parallel to and 60 to 70 km north of Puerto Plata. Ewing and Heezen (1955) noted a number of topographic features in the bottom of the Puerto Rico Trench which trend approximately N 55^{o}W, parallel to the northeast coast of Hispaniola. It is perhaps significant that the major antiformal structure, as well as the Camu, Tamarindo, and gravity slide faults in the Puerto Plata area have nearly the same trend.

Gravity data shown by Lyons (*in* Eardley, 1962) indicate an extension of the trench axis to the north of Hispaniola and a negative isostatic anomaly (about -60 mgal) for Puerto Plata and the northeast coast of Hispaniola. This is higher than the -180 mgal anomaly over Barbados on the raised southern extension of the trench. The writer suggests that this difference reflects the trench flank location of Puerto Plata as opposed to the trench axial location of Barbados.

Accepting Hess' (1938) general contention that trenches have a root and must be held down by downward stress for fairly long geologic periods, the writer was surprised not to find evidence of any significant folding in response to compressive forces. Instead, the geology of the Puerto Plata area indicates that extension, normal faulting, slumping and gravity sliding, and turbidity current deposition were the dominant tectonic processes. Studies of oceanic trenches indicate that normal faulting and slumping are important trench flank characteristics (Bowin *et al.*, 1966; Ross and Shor, 1965; Ludwig *et al.*, 1966).

Sykes and Ewing (1965, Fig. 1, p. 5070) plotted earthquake epicenters for the Caribbean region during the time interval 1950-1964 and noted a greater seismicity of the south side of the Puerto Rico Trench as compared to the north side, a trend which continues along the northeast coast of Hispaniola. The authors suggest (p. 5066) "that two or more seismic belts may converge at the eastern edge of Hispaniola." The writer postulates that one of these belts represents the fault trace of the south side of the present Puerto Rico Trench which passes through the Puerto Plata area.

GEOLOGIC HISTORY

During Late Cretaceous(?) volcanism, spilite, keratophyre and andesite flows, and tuffs of the Los Caños Formation were deposited on a serpentinite basement. As a thickness of approximately 4 km of volcanic rocks accumulated, the basal portions of the Los Caños were converted into glaucophane and actinolite schists. During folding of the Los Caños Formation near the end of Cretaceous time, slices of serpentinite basement, some intruded by gabbro and some containing metamorphosed blocks of lower Los Caños, were faulted into upper Los Caños rocks. Some serpentinites continued to move upward along faults until the Late Eocene.

Volcanism changed during Paleocene-Early Eocene time from intermixed flows and tuffs to entirely pyroclastic tuffs, although the environment was still submarine. The Imbert andesite and dacite tuffs were deposited unconformably on the Los Caños Formation. The markedly finer grain size and thinner beds of the Imbert Formation, as compared to the Los Caños Formation, indicate a more distant source of volcanism during Paleocene-Eocene time.

There are no Middle Eocene rocks *in situ*, although limestone blocks of this age are found as clasts in the San Marcos olistostrome. Since only basal units of the Imbert Formation were dated as Paleocene-Lower Eocene and only the upper portions of the Luperon Formation as Upper Eocene, either of these two formations may contain Middle Eocene rocks. The writer prefers the alternative that volcanism had ceased, that most of the area was still submerged (hence, little chance for subaerial erosion and deposition), and therefore, that a gap in the record is to be expected. In any case, volcanism ceased in the area at the end of the Early Eocene.

Sometime during the late Middle Eocene, a water-bearing tuffaceous layer either in or just above the Imbert Formation was triggered to liquifaction by earthquake shock. Moving down the trench slope, the aqueous tuffaceous layer gathered blocks of rocks contemporaneous with or older than the matrix, and was emplaced as the San Marcos olistostrome. Near the end of the late Middle Eocene, an episode of folding and faulting involved the Imbert Formation, the Los Caños Formation and the San Marcos olistostrome, so that by Upper Eocene time, portions of the area must have been above sea level in order to supply Imbert and Los Caños detritus to the Luperon Formation. Uplift of the coastal area from Late Cretaceous to late Middle Eocene probably took place primarily along the Camu Fault. Relative motion during this period was the reverse of that shown on Plate I, which indicates relative movement since the Middle Miocene.

The Late Eocene began with unconformable deposition of a basal conglomerate upon the Imbert Formation in the east and continued with turbidity current deposition of the rapidly alternating tuffaceous sandstones and shales of the Luperon Formation farther west. This formation contains the first undoubted stream-rounded clasts of older formations in the area. The Luperon Formation occurs entirely in the western portion of the map area, suggesting that in the central and eastern portions the surface was already domed into a general antiformal structure.

There is no rock record of the Early, Middle and most of the Late Oligocene. The Puerto Plata area underwent gentle upwarping from post-Late Eocene time onward. It remained a local high, while a large area to the south began to subside and receive sediments during Oligocene-Miocene time, an area which eventually became the mountains of the Cordillera Septentrional. Except for a few discontinuous basal conglomerates and calcareous marine shales, the Oligocene-Miocene sedimentary rocks in the north-central part of the Septentrional range are predominantly fossiliferous marine limestones. The Isla Limestone was formed during late Middle Miocene on a low-lying shoal west of Puerto Plata.

Sometime in post-Middle Miocene time, Septentrional rocks were gently folded and motion on the Camu Fault began again with the relative movement of south side up (Plate I), lifting Miocene rocks to elevations above 1000 m. During this uplift, the rocks which form Pico de Isabel de Torres became detached from the main Septentrional mass and moved as a slump unit to its present position.

Although not well dated, movement began on the Tamarindo Fault at about the time of the recurring motion on the Camu Fault. The Maimon graben and its associated fault breccias and sediments formed at a later time at right angles to the trends of the Camu and Tamarindo Faults. Shallow marine incursions have recurred in the Puerto Plata area from post-Miocene to Recent time, as documented by coral limestones along the north coast.

REFERENCES

Bermudez, P.J., 1949, Tertiary smaller foraminifera of the Dominican Republic: Cushman Lab. Foram. Research Spec. Publ. 25, p. 1-322.

Bowin, C., 1960, Geology of Central Dominican Republic: Unpublished Ph.D. Dissertation, Princeton University. 211 p.

________, and A. Nalwalk, 1963, Serpentinized peridotite dredged from the north wall, Puerto Rico Trench: Abstract, Amer. Geophys. Union, Trans., v. 44, p. 120.

________, A. Nalwalk, and J.B. Hersey, 1966, Serpentinized peridotite from the north wall of the Puerto Rico Trench: Geol. Soc. Amer., Bull., v. 77, p. 257-270.

Carlisle, D., 1963, Pillow breccias and their aquagene tuffs, Quadra Island, British Columbia: Jour. Geology, v. 71, no. 1, p. 48-71.

Caudri, C.M.B., 1944, The larger foraminifera from San Juan de los Morros, State of Guarico, Venezuela: Amer. Paleontology Bull., v. 28, no. 114, p. 355-412.

Challis, G.A., 1965, The origin of New Zealand ultramafic intrusions: Jour. Petrology, v. 6, Pt. 2, p. 322-364.

Chesterman, C.W., 1960, Intrusive ultrabasic rocks and their metamorphic relationships at Leech Lake Mountain, Medocino County, California: 21st Int'l Geol. Cong. Rept., Pt. XIII, p. 208-215.

De, A., 1960, Petrology of dikes emplaced in the ultramafic rocks of southeastern Quebec: Unpublished Ph.D. Dissertation, Princeton University.

Donnelly, T.W., 1963, Genesis of albite in early orogenic volcanic rocks: Amer. Jour. Sci., v. 261, p. 957-972.

Eardley, A.J., 1962, Structural Geology of North America: Harper & Row, New York, N.Y. 743 p.

Ewing, M. and B.C. Heezen, 1955, Puerto Rico Trench topographic and geophysical data: Geol. Soc. Amer. Spec. Paper No. 62, p. 255-267.

Flores, G., 1955, Definition of olistostrome: *in* Fourth World Petroleum Congress, Sect. 1, p. 122.

Gabb, W.M, 1873, On the topography and geology of Santo Domingo: Amer. Phil. Soc., Trans., New Series, v. 15, p. 49-260.

Green, D.H., 1961, Ultramafic breccias from the Musa Valley, eastern Papua: Geol. Mag., v. 98, p. 1-26.

Hess, H.H., 1938, Gravity anomalies and island arc structure with particular reference to the West Indies: Amer. Phil. Soc., Proc., v. 79, p. 71-96.

________, 1954, Geological hypotheses and the earth's crust under the ocean: Roy. Soc. of London, Proc., Series A, v. 222, p. 341-348.

________, 1955, the oceanic crust: Jour. Mar. Res., v. 14, p. 423-439.

________, 1959, The AMSOC hole to the earth's mantle: Amer. Geophys. Union, Trans., v. 40, p. 340-345.

________, 1960, Caribbean research project: progress report: Geol. Soc. Amer., Bull., v. 64, p. 1-6.

________, 1962, History of ocean basins: *in* Petrologic Studies, A Volume to Honor A.F. Buddington: Geol. Soc. Amer., p. 599-620.

________, 1964, The oceanic crust, the upper mantle and the Mayaguez serpentinized peridotite: *in* A Study of Serpentinite: Nat. Acad. Sci. Nat. Res. Coun., Publ. No. 1188, p. 169-175.

Kugler, H.G., 1953, Jurassic to Recent sedimentary environments in Trinidad: Bull. Assoc. Suisse des Geol. et Ing. du Petrole, v. 20, no. 59, p. 27-60.

Ludwig, W.J., J.I. Ewing, M. Ewing, S. Murauchi, N. Den, S. Asano, H. Hotta, M. Hayakawa, T. Asanuma, K. Ickikawa, and I. Noguchi, 1966, Sediments and structure of the Japan Trench: Jour. Geophys. Res., v. 71, p. 2121-2137.

Mattson, P.H., 1960, Geology of the Mayaguez area, Puerto Rico: Geol. Soc. Amer., Bull., v. 71, p. 319-362.

Palmer, H.C., 1963, Geology of the Moncion-Jarabacoa area, Dominican Republic: Unpublished Ph.D. Dissertation, Princeton University. 256 p.

Raleigh, C.B. and M.S. Paterson, 1965, Experimental deformation of serpentinite and its tectonic implications: Jour. Geophys. Res., v. 70, no. 16, p. 3965-3985.

Rigo de Righi, M. and F. Cortesini, 1964, Gravity tectonics in foothills structure belt of southeast Turkey: Amer. Assoc. Petroleum Geol., Bull., v. 48, no. 12, p. 1911-1937.

Ross, D.A. and G.G. Shor, 1965, Reflection profiles across the Middle America Trench: Jour. Geophys. Res., v. 70, p. 5551-5572.

Schlocker, J., 1960, Rodingite from Angel Island, San Francisco Bay, California: U.S. Geol. Survey Prof. Paper 400-B, p. 311-312.

Shagam, R., 1960, Geology of central Araqua, Venezuela: Geol. Soc. Amer., Bull., v. 71, p. 249-302.

Shand, S.J., 1949, Rocks of the Mid-Atlantic Ridge: Jour. Geol., v. 57, p. 89-92.

Sykes, L.R. and M. Ewing, 1965, The seismicity of the Caribbean region: Jour. Geophys. Res., v. 70, no. 20, p. 5065-5074.

Thayer, T.P. and P.W. Guild, 1947, Thrust faults and related structures in eastern Cuba: Amer. Geophys. Union, Trans., v. 28, no. 6, p. 919-930.

Vaughan, T.W., W. Cooke, D.D. Condit, C.P. Ross, W.P. Woodring, and F.C. Calkins, 1921, A geological reconnaissance of the Dominican Republic, geological survey of the Dominican Republic: Memoirs, vol. 1, prepared by the U.S. Geol. Survey, Washington, D.C. 268 p.

Ware, G.H., Jr., 1962, Rodingites and related rocks of the ultramafic masses, Puerto Plata, Dominican Republic: Unpublished B.S. Thesis, Princeton University.

Wilkinson, J.G.F., 1953, Some aspects of the Alpine-type serpentinites of Queensland: Geol. Mag., v. 90, p. 305-321.

Wise, D. and J.M. Bird, 1964, International Field Institute, Italy: Geotimes, v. 9, no. 5, p. 12-15.

GEOLOGY OF THE MONCION-JARABACOA AREA, DOMINICAN REPUBLIC

H. Currie Palmer
Department of Geophysics
The University of Western Ontario
London, Canada

CONTENTS

CONTENTS (continued)

LIST OF ILLUSTRATIONS

Figure

Plate

LIST OF TABLES

Table

ABSTRACT

The Moncion-Jarabacoa area is situated on the north flank of the Cordillera Central of the Dominican Republic. Volcanic, metavolcanic and plutonic igneous rocks underlie the major portion of the map area, which is approximately 2000 square km. The metavolcanic and volcanic rocks are divided into three formations separated by east-trending, high angle strike faults.

Mafic metavolcanic rocks of the Duarte Formation, which range in metamorphic grade from sub-greenschist facies to the amphibolite facies, underlie a large part of the map area. Sub-greenschist facies rocks are massive lavas and tuffs containing the minerals albite, clinopyroxene, chlorite, prehnite, pumpellyite and epidote; rocks of the greenschist facies are massive schistose greenstones consisting of actinolite, chlorite, albite and epidote.

In the northwestern part of the area the metabasalts of the Duarte Formation are separated from the schists of the Amina Formation by a narrow fault-bounded strip of Early Oligocene sedimentary rocks. Original tuffaceous sediments, or tuffs of intermediate-to-acid composition, of the Amina Formation were regionally metamorphosed to the greenschist facies and now occur as schists made up of varying proportions of epidote, chlorite, quartz and albite. Scanty paleontological evidence suggests that the Amina Formation and probably the Duarte Formation are pre-Middle Aptian-Albian in age. The age of the metamorphism is not known but is thought to have taken place prior to deposition of the Late Cretaceous Tireo Formation.

The greenschist facies rocks of the Duarte Formation are in fault contact in the southeastern part of the area with Late Cretaceous volcanic rocks of the Tireo Formation. This formation includes tuffs and porphyritic lavas of andesitic and quartz keratophyric composition.

Serpentinites, which possibly represent detached remnants of oceanic crust, occur between the Duarte Formation and Amina Formation (or the correlative of the latter in the central Dominican Republic). Two types of quartz diorite, with minor associated bodies of hornblendite, intrude the volcanic and metavolcanic formations. One type occurs as generally concordant, marginally foliated, leucotonalite plutons, which are only found intrusive into the greenschist facies rocks of the Duarte Formation, producing metamorphic aureoles in the lower part of the amphibolite facies. The second type is dominantly discordant hornblende tonalite plutons, some of which are of batholithic proportion, which were emplaced in the Tireo and Duarte Formations.

Intrusion of the hornblende tonalites was followed by uplift and erosion, which led to deposition of the unmetamorphosed Magua Formation of Late Maestrichtian (?) to Middle Eocene age. This formation consists of marine boulder-size conglomerate and breccia with minor limestone, mudstone and basaltic lava.

Following an episode of folding and erosion, the Los Caguelles Limestone Breccia, consisting largely of limestone fragments in a red hematitic matrix, was deposited probably during the Late Eocene. Lithic conglomerate, partly marine, of the Lower Oligocene Inoa Conglomerate occupies a graben between the Amina and Duarte Formations. The Inoa Conglomerate correlates with the marine Represa Conglomerate farther east. Marine sandstones and mudstones of the Velazquitos Formation, also of Early Oligocene age, lie conformably on the Inoa and Represa Conglomerates. Folding and high-angle faulting accompanied by tectonic movement of serpentinites took place between deposition of the Lower Oligocene formations and the Middle or Upper Oligocene Janico Formation and Moncion Limestone. The former consists of thin-bedded calcareous sandstones and mudstones, the latter of neritic limestone.

A minor angular unconformity separates Oligocene from Miocene rocks. The latter includes marine calcareous sandstones of the Cercado Formation and its basal Bulla Conglomerate Member.

INTRODUCTION

The area of study is situated on the north flank of the Cordillera Central of the Dominican Republic. This cordillera is the principal mountain range of Hispaniola, continuing westward from the Dominican Republic into Haiti where it is called the Massif du Nord. The intersection at 19°15'N, 71°W is in the west-central portion of the map area, which comprises approximately 2000 square km.

METHODS AND TERMINOLOGY

About ten months were spent in the field during the summer and fall of 1959 and 1960. Two of these ten months were devoted to reconnaissance outside the map area. All parts of the map area were not investigated in equal detail. Because of limited access, the southern and southwestern extremities of the map area were studied in reconnaissance only. Mapping of the Loma Caribe peridotite was completed by Bowin (1960), and consequently, field work in the east was concentrated in areas underlain by rocks other than the peridotite.

Mapping was done on air photographs (scale 1:60,000) taken in 1958 and 1959 and supplied by the Dominican government. For the initial report, which partially fulfilled requirements for the Ph.D. degree, Princeton University, an uncontrolled planimetric map was constructed from the photographs and reduced to 1:100,000. Subsequently, topographic maps have become available for the Dominican Republic. Original field data were transferred from the air photos to these maps (U.S. Army Map Service, Series E733; scale 1:50,000) and a new base map prepared and photographically reduced to the scale 1:100,000. This map is reproduced as Plate 1 of this report. Fossil localities referred to in the text are located with respect to grid coordinates as given on the Series E733 maps.

Laboratory studies were based on approximately 900 hand specimens and approximately 400 thin sections. Refractive indices of minerals were determined by the immersion method using sodium light. Optic axial angles were measured with a universal stage. X-ray diffraction work was done with a Norelco diffractometer using copper radiation and glass smear mounts. Mineral identifications were made at a machine speed of 1°/minute and lattice dimensions determined at ¼°/minute with an internal silicon standard.

In the descriptions of sedimentary rocks, bedding thicknesses are classified according to Dunbar and Rodgers (1957, p. 97), and clastic particles are classified on the Wentworth Grade Scale as given by Dunbar and Rodgers (1957, p. 161).

ACKNOWLEDGMENTS

It is a pleasure to acknowledge the advice and encouragement generously given by Professors H.H. Hess, J. Kalliokoski, F.B. Van Houten, and A.G. Fischer of the Geology Department, Princeton University. Professor Hess suggested the project and visited the writer in the field.

The success of research in a country foreign to the investigator is dependent upon assistance of many local residents. Edward F. Pawley, General Manager, and A.A. Weymouth, Chief Geologist of Minera y Beneficiadora Dominicana, provided innumerable services. Tomas Pastoriza loaned the writer a jeep for several days and otherwise aided the writer in problems connected with work in the Cibao region. Profitable discussions on Dominican geology were enjoyed with Dr. Pompillia A. Brouwer and Ing. Oscar Cucurullo, Jr. Cooperation was received from the Instituto Cartografico Universitario and its Director, Jose Joaquin Hungria. I thank the staff of Minera y Beneficiadora Falconbridge Dominicana for the use of drafting equipment and for other courtesies extended to the writer.

Professional assistance from the following paleontologists is gratefully acknowledged:

W.S. Cole, J.W. Wells, E.A. Pessagno, A.G. Fischer, J.H. Johnson, and W.A. Berggren.

Carl Bowin took time away from his own work to accompany the writer on his first trip to the Dominican Republic. Frederick Nagle provided field assistance and constructive criticism during the summer of 1959.

It is a pleasure to recall lively discussions held with fellow graduate students at Princeton in the early sixties who were studying various aspects of Caribbean and Andean geology. Among those who helped the writer sort out improbable models from probable ones were: R. Shagam, Lynn Glover, V.M. Seiders and A. Menendez.

Financial cost of the project was borne largely by the Caribbean Research Fund, Department of Geology, Princeton University. Drafting costs associated with the production of Plate 1 were met with a grant from Noranda Exploration Company, Ltd. The writer gratefully acknowledges the Canadian Alumni Association and Siscoe Fellowships held while at Princeton University.

INTRODUCTION TO STRATIGRAPHY

An interpretation of the stratigraphic sequence of the map area is given in Figure 1. Approximate positions on the time scale are given for the igneous rocks found in the map area. Stratigraphic relations and position of unconformities in the sequence are, in many cases, largely a matter of interpretation, as few of the successive units are in sedimentary contact. Furthermore, it is to be noted that the paleontological dates determined do not prove that the rock units represent the whole time interval assigned to them, nor do they necessarily indicate that rocks units of approximately the same age are time equivalents.

The oldest rocks in the map area, with the possible exception of the serpentinites which may represent detached fragments of oceanic crust, are considered to be the regionally metamorphosed Amina and Duarte Formations. The Amina Formation is composed of epidote-chlorite-albite-quartz schists. The Duarte Formation consists principally of mafic volcanic rocks metamorphosed to the prehnite-pumpellyite facies and the greenschist facies. The Amina and Duarte Formations are separated everywhere by a fault-bounded trough filled with Lower Oligocene sediments, and consequently the stratigraphic relationship between these two formations is uncertain. The lower-grade (prehnite-pumpellyite) rocks of the Duarte Formation are in close proximity to the greenschist facies rocks of the Amina Formation. If isograds parallel ancient isotherms, which in the simplest case would be convex upward, the structural relationships would suggest that the Amina Formation is stratigraphically below the Duarte Formation. This weak argument is completely invalidated if the Amina and Duarte Formations have not always occupied the positions they do now; the possibility that they have been brought together by large lateral translations cannot be dismissed.

The contact between the Duarte Formation and the Tireo Formation is a fault. An unconformity is believed to separate these units by virtue of the fact that plutons of leucotonalite are found only in the regionally metamorphosed Duarte Formation. Plutons of hornblende tonalite intrude both the Duarte and Tireo Formations and have characteristics indicating shallower depths of emplacement than do the leucotonalites. For this reason, a period of uplift and erosion is believed to have intervened between time of metamorphism of the Duarte Formation and time of deposition of the Tireo Formation. The age of the Magua Formation is poorly established, and consequently the time of emplacement of the hornblende tonalites, boulders of which are found in conglomerates of the Magua Formation, must be regarded as tentative.

AMINA FORMATION

The Amina Formation is named for the Rio Amina along which almost continuous outcrops of the formation are exposed. The southern contact of the formation is a fault, which places the formation in contact with rocks of the Las Matas Breccia and the Inoa Conglomerate of Early Oligocene age. To the north the formation is overlain unconformably by the Moncion

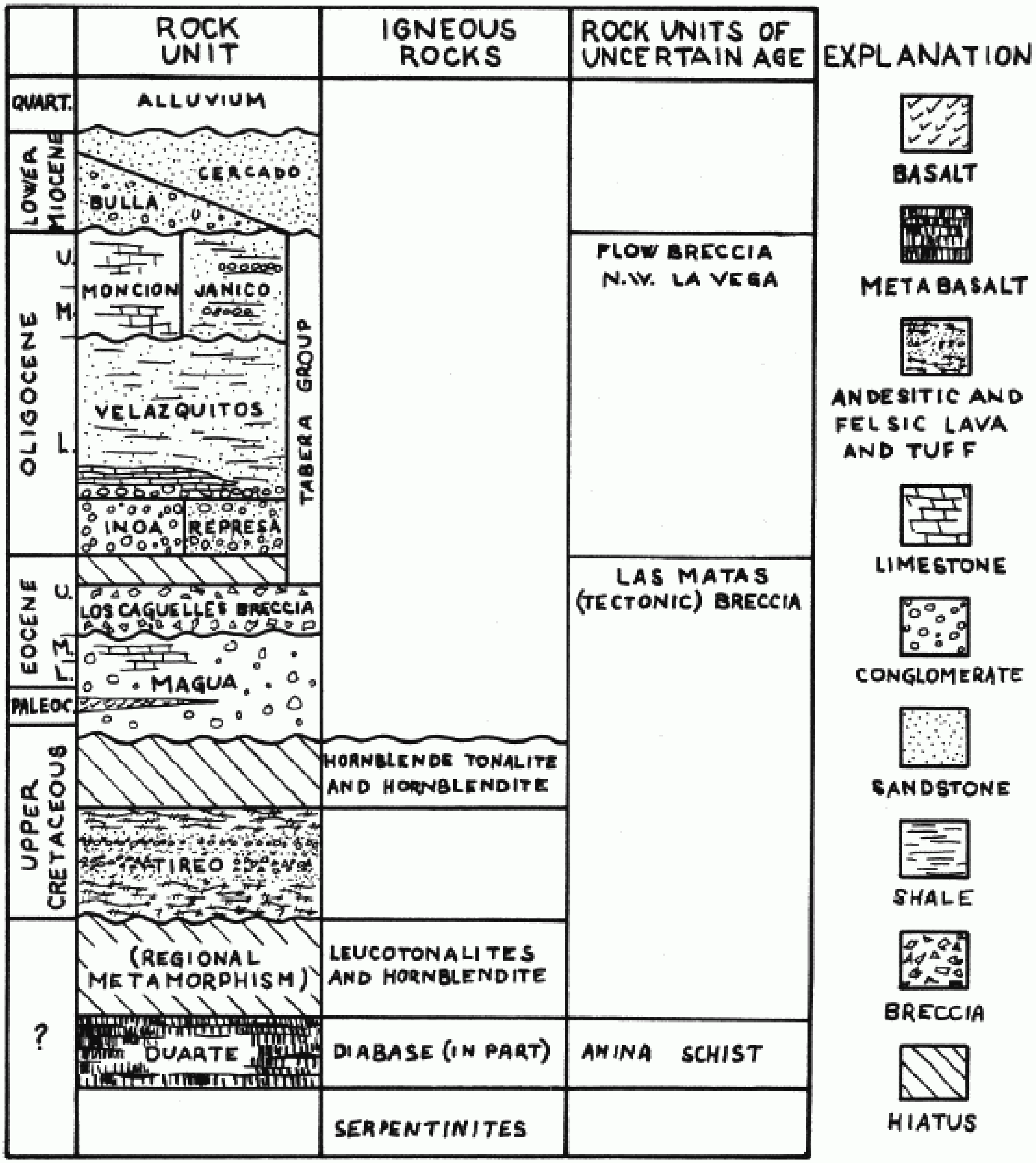


Figure 1. Stratigraphic sequence for the Moncion-Jarabacoa area.

Limestone of Middle or Late Oligocene age and by the Bulla Conglomerate and Cercado Formation of Early Miocene age.

The Amina Formation consists of grayish-green schists with the following principal minerals: albite, quartz, chlorite, epidote, actinolite (minor and only locally developed), and muscovite (minor and only locally developed). The more ferromagnesian-rich schists are generally finely foliated and consist of 70% chlorite and epidote, with or without actinolite, and 30% quartz and albite. Most of the rocks are richer in quartz and albite; some contain as much as 75% of these minerals. Whenever the leucocratic minerals exceed 50% of the rock, actinolite is absent. Very minor in amount are epidote-muscovite-albite-quartz schists.

In the leucocratic varieties, schistosity is produced by a flattening of the quartz and albite grains in the plane of foliation and by chlorite shreds aligned in this plane. In the ferromagnesian-rich schists, which are generally finer-grained than the quartzo-feldspathic schists, foliation is marked by a thin and diffuse concentration of light and dark minerals in alternating laminations. There are all gradations between these thinly laminated chlorite schists and rocks in which quartz and albite are concentrated in distinct light-colored layers up to 1-2 cm in thickness. Ferromagnesian minerals, chlorite and epidote, are concentrated in the intervening dark layers. This separation is not entirely complete; each of these assemblages (quartz + albite, or chlorite + epidote) contains the minerals that dominate the other.

The only other lithology present within the formation is marble, which occurs as a 60-m thick lens. It is exposed at two places in the Rio Amina (stations 2891/21416 and 2905/21418) and from air photo interpretations is estimated to have an outcrop length of 2 km. In hand specimen the marble varies from white recrystallized limestone to a mottled type with irregularly distributed carbonaceous (?) material. Vein quartz commonly occurs as lens-like masses parallel to foliation of the schists. This vein quartz is very resistant to weathering and forms a pavement on top of bedrock in flat upland areas.

Metamorphism

Metamorphism of the Amina Formation was sufficiently intense to destroy original textures. In only one of ten thin sections examined from rocks of the formation is there any suggestion of original clastic textures. Typically, the constituent minerals are welded together, producing an interlocking metamorphic fabric. Presence of chlorite and muscovite and absence of biotite indicate that the grade of metamorphism is less than that of the biotite zone. The assemblages chlorite-epidote-albite-quartz (actinolite) and quartz-albite-muscovite-epidote (chlorite) are common assemblages of the greenschist facies of metamorphism (Turner, 1968).

Origin

In contrast to the greenschists of the Duarte Formation, no textures or structures characteristic of lavas are present in the rocks of the Amina Formation. The most ferromagnesian-rich schists of the Amina Formation differ mineralogically from the greenschists of the Duarte Formation in having only small amounts of actinolite and considerable free quartz, a mineral only present in amygdules of the Duarte lavas. Chlorite schists of the Amina Formation may represent tuffs of andesitic-to-dacitic rather than basaltic composition.

The rocks in which quartz and albite form 50% or more of the rock are very similar to those described by Hutton (1940) from western Otago. Hutton was able to trace these schists through zones of decreasing metamorphism into only slightly altered graywackes. The leucocratic schists bearing muscovite and little chlorite are mineralogically similar to but texturally unlike the quartz keratophyres of the Maimon Formation of Bowin (1966).

Age and Correlation

No fossils have yet been found in the formation. The one limestone lens is completely recrystallized.

To the north the formation is overlain unconformably by Oligocene limestone and Miocene conglomerates and sandstones. To the south it is in fault contact with conglomerates of Oligocene age.

The Amina Formation is most probably correlative with the Maimon Formation of Bowin (1966). From a petrographic standpoint they are somewhat different. The sericitic quartz-albite rocks of the Maimon Formation are not present in the Amina Formation. The former rocks have quartz with euhedral outlines, indicating that they are metaquartz keratophyres. Where white mica is present in the Amina Formation, it is well crystallized muscovite accompanied by epidote, and quartz is invariably anhedral. The other major rock type from the Maimon Formation more closely resembles rocks of the Amina Formation. In describing them Bowin (1966, p. 25) states: "Thin section and x-ray diffraction work shows them to be composed of albitic plagioclase, epidote, quartz, chlorite and amphibole in order of decreasing abundance." The present writer has examined the westernmost exposures of the Maimon Formation, has studied thin sections from these rocks, and finds them to be very similar to rocks of the Amina Formation.

Considerations of the regional geology tend to support this correlation, in that the Maimon and Amina Formations occupy similar structural positions. In the area mapped by Bowin two groups of regionally metamorphosed rocks, called the Duarte and Maimon Formations, are separated by a long body of serpentinized peridotite. The northern formation (Maimon) is thrust in a northeasterly direction over unmetamorphosed rocks ranging in age from Late Early Cretaceous to Middle Eocene. The Duarte Formation, which occurs in a belt south of the peridotite, continues along strike into the area of this study. The position of the peridotite in the present area is occupied by a graben of sediments with minor pods of serpentinite, and the north boundary of the graben is formed of the Amina Formation.

Minimum age of the Amina Formation is therefore based on two assumptions: (1) that because the metamorphosed Maimon Formation is thrust over the unmetamorphosed Middle Aptian-Middle Albian Hatillo Limestone, the Maimon Formation is pre-Middle Albian in age; and (2) that the Amina Formation is correlative with the Maimon Formation. If both these assumptions are correct, then a pre-Middle Albian age is indicated for the Amina Formation.

DUARTE FORMATION

Sub-Greenschist, Greenschist and Amphibolite Facies

Bowin (1966) proposed the name Duarte Formation for schistose and massive, regionally metamorphosed, mafic volcanic rocks exposed in a belt extending northwest of Santo Domingo to the town of Jarabacoa. They were described as consisting of varying proportions of amphibole, epidote, chlorite, plagioclase and opaque oxide.

Mapping in the area of study has shown that the Duarte metavolcanic rocks of greenschist metamorphic facies extend an additional 75 km to the west-northwest. In the western part of the map area basic volcanic rocks of metamorphic grade less than that of the greenschist facies are found. These rocks are principally basic flows and flow breccias consisting of albite, clinopyroxene and chlorite. Concentrated principally within amygdules, several of the following minerals typically occur: chlorite, epidote, albite, calcite, quartz, analcime, prehnite, and pumpellyite. These rocks are shown on Plate 1 as Duarte rocks of sub-greenschist facies. In this western part of the map area the isograd between rocks of the greenschist facies and rocks of the sub-greenschist facies is sharply defined. Transition is manifested by a change in color from light to dark gray or reddish-gray to greenish-gray. The greenish color correlates with replacement of clinopyroxene by actinolite, which is totally complete within several hundred meters of the isograd.

In the eastern part of the map area a second area of sub-greenschist facies rocks is mapped as part of the Duarte Formation. Part of this area had previously been mapped by Bowin (1966) as "Rocks Northeast of Jarabacoa." These rocks differ from the sub-greenschist facies rocks in the western part of the present map area in several respects. Although clinopyroxene-bearing basic lavas are present, most of the lavas examined have incipient replacement of the pyroxene by actinolite regardless of their proximity to the surface trace of the isograd. In the western sub-greenschist facies region, first appearance of actinolite takes place close to the isograd, and at the isograd replacement of clinopyroxene by actinolite is complete. Secondly, metatuffs ranging in color from yellow-green to dark green are much more abundant in the eastern sub-greenschist region. The yellow-green metatuffs are massive-to-very-weakly schistose and are extremely fine-grained. Their mineralogy was studied by a combination of thin section and x-ray diffraction methods. Minerals common to all these rocks are clinopyroxene, plagioclase, chlorite and actinolite. Also present are two or three of the following: epidote, prehnite, pumpellyite, quartz, calcite, and sericite. The darker-green metatuffs are richer in chlorite, and many appear to be basic vitric tuffs, inasmuch as shard textures flattened in the plane of schistosity are still visible in many of these rocks. These rocks consist mainly of chlorite and actinolite; in some specimens small amounts of calcite are also present. Mineralogy of these rocks is appropriate for inclusion within the greenschist facies. It is believed that the original glassy nature of these rocks made them particularly amenable to metamorphism. They are intimately associated with tuffs and lavas, which were originally holocrystalline and which still retain original clinopyroxene together with the metamorphic minerals prehnite and pumpellyite. Thus, the sub-greenschist - greenschist isograd in the eastern region is based upon complete replacement of clinopyroxene by actinolite and by absence of prehnite and pumpellyite in original holocrystalline rocks.

Approximately 95% of the rocks of the greenschist facies are massive-to-moderately-schistose, greenish-gray greenstones. The majority of these are composed of varying but essential proportions of actinolite, chlorite, albite and epidote. Amygdules, where present, are filled with one or more minerals: quartz, chlorite, epidote, or calcite. Analcime, prehnite and pumpellyite are absent.

More mafic types of greenstones also occur. These are massive Fe-Ti oxide-bearing chlorite-tremolite greenstones and chlorite-actinolite schists, some of which have small amounts of albite and sphene. Such greenstones have analogues within the less metamorphosed sub-greenschist facies terrain. A sample collected at 2994/21365 within the area of sub-greenschists, although incipiently altered by its proximity to the Las Placetas Batholith, illustrates volcanic parentage of these more mafic greenstones. Rocks at the outcrop from which this sample was taken are black with white amygdules forming ¼ the volume. As seen in thin section, they are composed of 75% zoned calcic diopside ($2V_z$=61.4°-57.3°, Ny=1.630), 15% chlorite with a trace of interstitial plagioclase, and a few fibres of actinolite. Amygdules are filled with calcite, weakly birefringent analcime and sericite.

Within the area of greenschist facies, rocks of yet higher metamorphic grade are represented by amphibolites associated with intrusions of leucotonalite (Fig. 2), and basic hornfels surrounding masses of hornblende tonalite which also intrude the formation. These rocks are described herein, but in view of the scale of field mapping, only one area underlain by amphibolites, in the Jagua Abajo, is indicated on Plate 1. This area encompasses thermal aureoles of three leucotonalite plutons near the settlements of Pinalito, Los Pilones and El Papayo and extends westward 1 km or less beyond the Rio Jagua, where layered gneisses formed of alternating layers of amphibolite and quartz-plagioclase (minor hornblende) rocks crop out intermittently over a distance of approximately 1½ km. At one locality in the river there is a conformable sheet of hornblende tonalite approximately 100 m thick, which, along with leucocratic layers within the amphibolites, is believed to represent the upper portions of a subjacent hornblende tonalite mass. Rocks within the Jagua Abajo area include rocks metamorphosed by leucotonalite in the east and possibly hornblende tonalite in the west (Fig. 3).

Figure 2. Leucotonalite injected along foliated planes of amphibolites. Northern contact of the Pinalito Pluton with Duarte country rocks in the Rio Baiguaque. Hammer for scale.

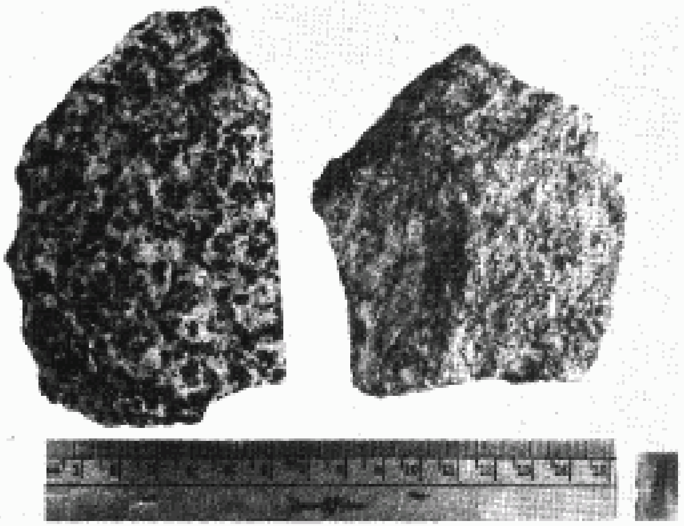


Figure 3. Hand specimens of quartz diorites. Left: hornblende tonalite. Right: leucotonalite.

Both in the Jagua Abajo area and other locales near leucotonalite bodies, grain size of the Duarte rocks increases, and schistosity or compositional layering of light and dark minerals becomes prominent. Transition from greenschist facies rocks to rocks of the amphibolite facies is characterized by two mineralogical changes: (1) conversion of greenstone chlorite and actinolite to an amphibole with distinct blue-green absorption parallel to the Z axial direction, and (2) an increase in calcium content of the plagioclase, so that oligoclase or oligoclase-andesine is the typical plagioclase of the inner part of the aureoles.

Quartz is released by both these reactions and was found in all thin sections of amphiboles examined. Epidote persists in the amphibolites, and biotite is sporadically developed in very small amounts.

Megascopically, the color of the aureole rocks is distinct from those of the greenschist facies. By virtue of the disappearance of chlorite and the formation of hornblende in place of actinolite, the rocks lose most of their greenish hue. Because of gneissic texture, overall color cannot be defined but is that of its component minerals: black hornblende with intervening streaks of white plagioclase and quartz. In many amphibolites amphibole forms 80% or more of the rocks, and they are black.

Mineral assemblages found in Duarte rocks of the amphibolite facies are as follows:

(1) blue-green hornblende - quartz - (oligoclase - andesine) - epidote
(2) blue-green hornblende - quartz - epidote
(3) blue-green hornblende - quartz-albite-cummingtonite
(4) greenish-blue hornblende - quartz - oligoclase - biotite - garnet - cummingtonite

Minor Lithologies within the Duarte Formation

Bedded cherts crop out at several localities within the Duarte Formation and have been found interbedded with basic rocks in all three facies of metamorphism. Maximum strike length over which the bedded cherts have been traced is approximately 2 km, and these rocks have not been found in sections exceeding 100 m in thickness. At the settlement of Los Caguelles (3070/21331), bedded cherts (bedded on the scale of 2-7 cm) are found interbedded with spilitic lavas; these cherts appear to be correlative with bedded cherts in the Rio Jagua (3083/21320), which are enclosed by amphibolitic rocks. Bedded cherts are also exposed within greenschist facies rocks between 3143/21323 and 3162/21313 and in the eastern sub-greenschist region at localities 3370/21200 and 3375/21205.

Carbonaceous quartz - muscovite-chlorite schists are exposed in several outcrops in the Rio Guanajuma east of Los Pilones, and carbonaceous quartz - calcite - chlorite schists and phyllites are exposed in the Rio Yami at 3305/21240.

Mottled silvery and pink muscovite - quartz schists crop out over a distance of approximately 2 km near Rincon Llano (3054/21208 to 3070/21216). On surfaces of hand specimens cut perpendicular to schistosity, these rocks show clear subcircular crystals of quartz 5 mm or less in diameter in a fine cream-colored matrix. In thin section the groundmass is composed of tiny (less than 0.04 mm) polygons of quartz with flakes of sericite between grain boundaries. Larger sheaves of muscovite and red hematite define the schistosity. In mineralogy these rocks are similar to the hydrothermally altered quartz keratophyres described by Donnelly (1959, p. 123) from the U.S. Virgin Islands.

Buff weathering, olive-gray where fresh, calcareous slates crop out over an extensive area centered around the settlement of El Cafe in the eastern part of the map area. Cleavage is essentially parallel to bedding, where layers rich in carbonate and rare sandy beds occur. Bedding in the sandy layers is on the scale of 5-8 cm. In the more calcareous beds cleavage is less well developed; the sandy beds are semi-schists. X-ray diffraction of the slates revealed presence of calcite, quartz, feldspar and 10A° mica. Thin section examination of two of the calcareous sandstones showed rock and mineral fragment components ranging in size from 2 to 0.1 mm and set in a matrix of calcite which formed approximately 35% of the rock. Rock fragments included polygranular aggregates of chert, phyllite and quartz - albite fragments, which are pieces of keratophyre or amygdule fillings from basic lavas.

Mineral grains included quartz, weathered or sericitized plagioclase, fresh albite, and minor amounts of chlorite, epidote and clinopyroxene. Because many of these detrital grains are of types found in the Duarte lavas, it is possible that an unconformity may exist between the volcanic rocks and these calcareous slates. More detailed mapping will be required to establish stratigraphic relationships between the slates and volcanics of the Duarte Formation.

Chemistry of the Duarte Formation

A number of alkali analyses were made of rocks from the greenschist and amphibolite facies of the Duarte Formation. The analyses were performed following the procedure of Brannock and Berthold (1953) using a Beckman D-U flame photometer. National Bureau of Standards granite (G-1) and diabase (W-1) were run as check samples on the analytical procedure. K_2O and Na_2O values found in these standards were within the range reported by a number of analytical laboratories (Stevens and Niles, 1960). Results of the alkali analyses from the Duarte metabasalts are given in Table 1:

Sample #		Grid Location	%Na_2O	%K_2O
CP-480	chlorite - tremolite greenstone	2817/21397	0.1	<0.1
CP-960	chlorite - tremolite greenstone	2709/21443	0.1	<0.1
CP-814	epidote - chlorite - albite actinolite greenstone	2832/21388	3.7	0.3
CP-227	epidote - chlorite - albite actinolite greenstone	3063/21292	3.7	0.15
CP-210	albite - chlorite - actinolite schist	3088/21257	2.0	0.1
CP-211	albite - chlorite - actinolite schist	3088/21257	1.9	0.1
CP-439	epidote - quartz - albite - chlorite - actinolite schist	2893/21215	1.7	0.15
CP-443	epidote - quartz - oligoclase hornblende schist (amphibolite)	2891/21231	2.8	0.1
CP-444	epidote - quartz - oligoclase hornblende schist (amphibolite)	2905/21236	2.9	0.15

Table 1. Alkali analyses of Duarte Formation metavolcanics.

The chlorite - tremolite greenstones are extremely low in both soda and potash and are believed to represent metamorphosed equivalents of clinopyroxene-rich lavas. All rocks analyzed are extremely low in potash, when compared to continental tholeiites (Green and Poldervaart, 1955); however, they are similar in K_2O content and Na_2O/K_2O ratios to oceanic tholeiites dredged from the Mid-Atlantic Ridge and East Pacific Rise (Engel *et al.*, 1965). Melson and Van Andel (1966) have shown that greenschist facies metabasalts from the Mid-Atlantic Ridge, when compared to unmetamorphosed tholeiites from ocean basins, are depleted further with respect to K_2O. None of the sub-greenschist facies lavas of the Duarte Formation were analyzed, and the importance of potassium loss during metamorphism cannot be evaluated. Overall low potassium contents in these rocks, however, are thought to reflect their affinities with primitive oceanic tholeiites.

Metamorphism

Metamorphic minerals characteristic of the sub-greenschist facies of the Duarte Formation are: albite, prehnite, pumpellyite, epidote and chlorite. These minerals are characteristic of the prehnite - pumpellyite metagraywacke facies as defined by Coombs (1961). In the greenschist facies of the Duarte Formation prehnite and pumpellyite are absent. Principal assemblages of the greenschist facies are: actinolite - chlorite-albite - epidote and actinolite or tremolite - chlorite (albite-sphene). In some localities transition from greenschist facies to amphibolite facies is bridged by the assemblage hornblende - albite - quartz - epidote, which represents the epidote-amphibolite facies of Eskola (1939). Generally, however, the transition from the greenschist facies to amphibolite facies (represented by the assemblage hornblende - (oligoclase - andesine) - quartz - epidote) is direct without an intervening epidote-amphibolite facies.

Available evidence suggests that the facies developed are those which are produced during conditions of relatively high geothermal gradient, similar to the facies series developed in the Abukuma Plateau of Japan (Miyashiro, 1961, 1968). The fact that (1) the pumpellyite in the sub-greenschist facies is a strongly pleochroic type, and (2) an index of refraction determination made indicates a pumpellyite rich in Fe^{+3} supports this type of facies development. In terrains where high pressure facies series occur, prehnite is not typically present and pumpellyite is poor in Fe^{+3} (Seki, 1961). Garnet was found in only one of the amphibolites, whereas cummingtonite was found in several amphibolites. Shido (1958) has shown that cummingtonite in medium-grade amphibolites is favored by relatively low-pressure types of facies series. Characteristic of these lower pressure facies series are abundant intrusions of granitic rocks (Miyashiro, 1961). These are represented in the Dominican Republic by leucotonalites, which are restricted to the greenschist facies of the Duarte Formation, were probably intruded during the main period of metamorphism, and served locally to increase the grade of metamorphism to that of the amphibolite facies. Also typical of this relatively low-pressure type metamorphism are granitic rocks, which are not confined to the metamorphic terrain (Miyashiro, 1961, p. 281). These are represented in the Dominican Republic by hornblende tonalites, some of which are of batholithic proportions.

Environment of Deposition and Age

Pillow structures have not been observed in the lavas; however, presence of bedded chert within the formation indicates marine deposition. Minor amounts of carbonaceous phyllite and schist suggest that reducing conditions prevailed locally. Na/K ratios in the lavas suggest that these rocks are similar to oceanic tholeiites that form most of the deeply submerged volcanic features in ocean basins (Engel *et al.*, 1965).

No fossils have been found from rocks of the Duarte Formation. The Magua Formation contains boulders of Duarte rocks and tonalite which intrude the Duarte Formation. Within the Magua Formation are bioclastic limestone lenses bearing Upper Cretaceous rudistids. Limestone fragments of the Los Caguelles Limestone Breccia bearing species of the pelagic foraminifer *Globotruncana* must have been derived from a limestone which overlay the Duarte Formation. From these lines of evidence the Duarte Formation is Late Cretaceous or older. From structural evidence, degree of metamorphism, and similarities with the Bermeja Complex of Puerto Rico, Bowin (1966) suggested a pre-Middle Albian (?) age for the Duarte Formation. His pre-Middle Albian (?) age estimate remains the best available.

TIREO FORMATION

The Tireo Formation was described by Bowin (1960, 1966) and is named for the community of Tireo situated in the valley of the Rio Tireo between the settlement of El Rio and the town of Constanza. Owing to limited access and ruggedness of terrain, the formation was studied in reconnaissance by Bowin. This writer devoted only a few days' field work to a study of that portion of the formation which appears on Plate 1.

The base of the formation is not exposed. To the east, the formation is in fault contact with the Duarte Formation of Bowin (1966), and in the area of this study it is in fault contact with the greenschist facies of the Duarte Formation. Principal rock types of the formation as described by Bowin are: (1) coarse-to-fine tuff; (2) lapilli tuff; and (3) quartz keratophyre.

That portion of the Tireo Formation within the map area is characterized by coarse-to-fine tuff, lapilli tuff and andesitic(?) lavas. The most common color of these rocks is light-to-medium gray.

The lavas of the Tireo Formation are distinguished from lavas of the sub-greenschist facies of the Duarte Formation by their lighter color and by the common presence of porphyritic texture. Lavas within the map area, which have been studied petrographically, show the effects of contact metamorphism by the Los Dajaos hornblende tonalite pluton. These rocks contain glomerophenocrysts of sericitized plagioclase in a groundmass of subequal amounts of plagioclase and actinolite. Chlorite and epidote form a minor amount of the rock, and opaque oxides are accessory minerals. From the proportion of plagioclase to actinolite these rocks appear to have been andesites rather than basalts. A lava collected south of the map area better illustrates the regionally unmetamorphosed character of the formation. In contrast to lavas within the map area, this rock has phenocrysts of augite in a light reddish-gray matrix. In thin section the rock shows euhedral phenocrysts of clinopyroxene up to 4 mm in maximum intercept diameter. The clinopyroxenes are pale yellow, strongly zoned and constitute 25% of the rock. Also present are a few microphenocrysts of olivine. Groundmass consists of clear laths of labradorite (An 65±5) ranging from 0.5 to 0.05 mm in length. Opaque oxides constitute 4-5%.

The coarse tuffs and lapilli tuffs show varying proportions of vitric, lithic and crystal components. Vitric components are subangular, undeformed fragments devitrified to chlorite and show delicate compositional banding in shades of light green to greenish-brown. Lithic components are dominantly vitrophyric rock types with microphenocrysts of plagioclase and clinopyroxene. The vitric part of these rocks and the matrix between clastic components have altered in part to prehnite, pumpellyite, laumontite, and a green mineral with higher birefringence than chlorite. This may be celadonite or stilpnomelane (?).

The minerals prehnite, pumpellyite and laumontite appear to be restricted to tuffaceous rocks of the formation. Limited data available suggest that the holocrystalline lavas have not been affected by diagenetic or low-grade metamorphic alteration. Epidote occurs only in thermal aureole rocks of Los Dajaos hornblende tonalite pluton, in agreement with the observation of Bowin (1966, p. 46), who reports that epidote is present only in rocks close to hornblende tonalites or in rocks close to the Bonao Fault.

Age of the Tireo Formation

The writer has no new paleontological evidence bearing on the age of the Tireo Formation. Bowin (1966, p. 48) found foraminifera in Tireo limestones at two widely separated localities. The assemblage at one locality yielded a probable Cenomanian age, whereas material from the other locale yielded a Middle Campanian-to-Early Maestrichtian age. Thus, rocks of the Tireo Formation appear to represent most of Late Cretaceous time.

MAGUA FORMATION

The Magua Formation is named for the Rio Magua along which a partial section is well exposed. An excellent partial section crops out in the Rio Mao, and more accessible sections are exposed along the road from Moncion to Las Mesetas and along the road south of El Rubio.

The Magua Formation consists dominantly of a sequence of well indurated lithic conglomerates with lesser amounts of basaltic volcanic breccias, limestone, sandstone and sandy mudstone. A single zone of basaltic lava was mapped within the formation and is herein referred to as the Rodeo Basalt of the Magua Formation.

The base of the formation was observed only in one locality along the abandoned road from Moncion to Jicome, but inasmuch as the Duarte rocks lack foliation at this outcrop and the conglomerates of the Magua Formation are very poorly bedded, no structural discordance between the two formations could be proven. The contact is considered to represent a major unconformity, however, because the conglomerates contain boulders of Duarte greenstones and boulders of tonalite which intrude the Duarte Formation. From the map pattern the Magua Formation appears to be preserved in the southern limb of a syncline plunging to the northwest. Thickness of the formation does not exceed 2000 m.

Conglomerates and Breccias

Conglomerates of the formation are typically gray, poorly sorted, poorly stratified, and characteristically have a large portion of subangular cobbles and boulders. Texture of the conglomerates ranges from intact to disrupted. In those with an intact texture the number of grade classes represented within any single outcrop is large. Commonly, there is a range in clast size from 45 cm to sand-sized matrix. Maximum observed size of boulders was 1.5 m. Conglomerates exhibiting a disrupted textural framework contain boulders commonly

30-60 cm in diameter in a matrix of pebbly sandstone or mudstone with very few clasts in the cobble size represented. Generally, clasts derived from rocks which crop out near the Magua-Duarte contact are more angular than clasts derived from more distant sources, i.e., hornblende tonalite. On the basis of field observation, the most common rock types represented as clasts in the conglomerates are rocks of all facies of the Duarte Formation, followed in approximate descending order of abundance by hornblende tonalite, chert, leucocratic volcanics, sandstone and shale (Fig. 4).

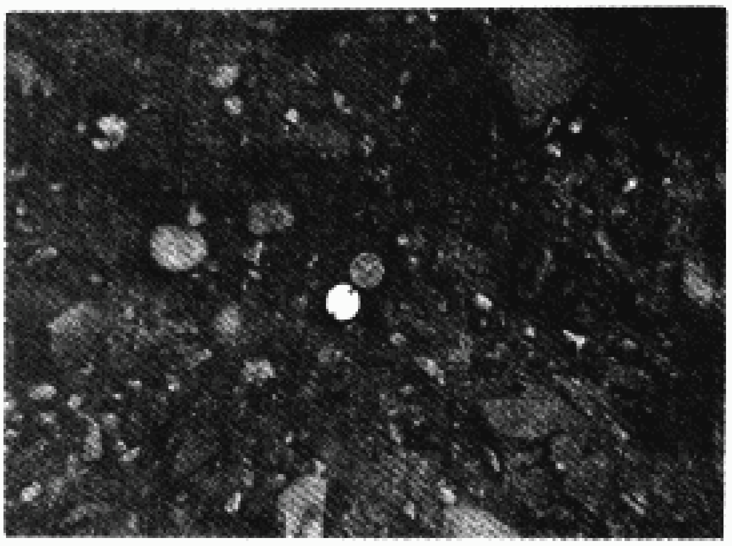


Figure 4. Magua conglomerate near base of formation south of Rodeo. Light-colored pebbles are tonalite; angular cobbles are Duarte greenstones. Compass for scale.

Breccias of the formation are particularly well exposed in the upper reaches of the Rio Guanajuma south of the village of El Rubio. These consist almost entirely of dominantly angular fragments of basalt ranging in size from less than 1 cm to 20 cm in diameter. Embedded within these breccias are pebble- to boulder-sized clasts of detrital material derived from the same rock types which supplied the clasts of the conglomerates of the formation (Fig. 5).

Figure 5. Sedimentary breccia of the Magua Formation south of Las Mesetas. Hammer on light-colored tonalite clast in center for scale.

Limestones

Limestones within the formation are of three main types: limestone conglomerates, bioclastic limestone, and massive- to thin-bedded aphanitic limestone. Conglomerates composed entirely of limestone pebbles have been observed in the Arroyo Pananao (2798/21419) and in the Rio Mao immediately south of the Inoa Fault. Conglomerate in the Arroyo Pananao consists of medium gray aphanitic limestone cobbles in a lighter-gray limestone matrix. All cobbles are texturally similar and in thin section show pelagic foraminifera and micropellets of calcite in an aphanitic base. Conglomerates in the Rio Mao show greater textural variation in the type of limestone clasts and also contain variable amounts of other rock types as clasts. With decrease in the number of limestone clasts, limestone conglomerates grade into lithic conglomerates lower in the section. Massive, gray or mottled white and gray bioclastic limestones occur as lenses within the lithic conglomerates and form hills up to several hundred meters in length. These limestones are composed of rudistid fragments and other pelecypods, echinoid spines, and a few foraminifera in a cryptocrystalline calcite matrix. Many samples of this type are partly recrystallized with veins of coarsely crystalline calcite. Massive- to thin-bedded and intensely sheared and crumpled limestones crop out along the road from Moncion to Las Mesetas north of the Rodeo Basalt Member. Northernmost exposures are of a mottled white and gray marble, which is also present north of Rodeo and in the Rio Mao. In the Rio Mao unsheared Inoa Conglomerate is in contact with this sheared marble, which grades southward into less sheared and finally into unsheared limestone pebble conglomerate. East of the Rio Mao toward Los Brujas, the character of the limestone changes; degree of recrystallization is less pervasive, and isolated blocks of aphanitic limestone are preserved between the shear planes.

Sandstones and Sandy Mudstones

Approximately 30 m of thin-bedded (3-8 cm) gray sandstones and calcareous mudstones are exposed in the Rio Guanajuma immediately south of the bridge on the road south of El Rubio. A similar 25-m thick sequence of calcareous fine-grained sandstones and sandy mudstones is exposed approximately 150 m south of fossil locality 2820/21407. Many of these fine sandstones and sandy mudstones, which have been traced along strike for approximately 600 m, have unidentifiable plant debris on bedding surfaces. On cut surfaces the sandy mudstones show graded laminae of sand and disruption of this lamination by burrows. In thin section the mudstone laminae show poorly preserved pelagic foraminifera, calcite-replaced radiolaria, and circular cross sections of siliceous sponge (?) spicules.

Rodeo Basalt Member

The Rodeo Basalt has been mapped along strike for approximately 9 km and has a minimum thickness of 100±20 m in the Rio Magua. The number of flows constituting the member was not determined. In thin section samples of the Rodeo Basalt resemble the vitrophyric lavas of the Duarte sub-greenschist facies and consist of microporphyritic aggregates of clinopyroxene set in a groundmass of plagioclase microlites and devitrified glass. Patches of chlorite, probably after olivine, together with tiny opaque oxides peppered throughout the devitrified glass form the remainder of the rock. Amygdule fillings include clear untwinned albite, chlorite, epidote, and slightly birefringent analcime.

Environment of Deposition and Origin

Much of the clastic debris of the conglomerates can be assigned to known lithologic types within the Duarte Formation or to rocks intrusive to that formation. Limestone cobbles in the conglomerates may be largely intraformational in origin. Source of the shale and phyllitic shale, the graywackes, and the leucocratic tuff fragments is not known. Intrusive feeders for the Rodeo Basalt and the basaltic volcanic breccias were not located; they may be beneath the younger Inoa Conglomerate.

Coarseness of the debris and angularity of many of the cobbles and boulders indicate existence of a rugged source area and very short or negligible subaerial transport to the basin of deposition. Some of the very angular clasts may have been transported to the edge of the depositional basin by some type of mass transport mechanism.

Presence of pelagic foraminifera and radiolaria and absence of benthonic fauna in the sandy mudstones are suggestive of a deep-water environment of deposition. Paucity of observable bedding in the conglomerates, poor sorting of the conglomerates and absence of sedimentary structures in the sandstones indicative of shallow-water deposition also favor a depositional environment below wave base. Submarine sliding was probably the principal mechanism of conglomerate transport to its ultimate basinal resting place. Bioclastic limestone lenses with their neritic fauna appear to be of shallow-water origin and are in sharp contrast to other rock types which appear to be of deep-water origin. One of these bioclastic limestone lenses lies stratigraphically less than 150 m above radiolaria-bearing mudstones. Bioclastic limestone lenses probably represent slide masses from contemporaneous limestone reefs which grew along the margins of the depositional basin. Alternatively, they could represent large allochthonous blocks from some pre-existing formation. A measure of support for their being contemporaneous reefs is afforded by the fact that large blocks of other lithologies have not been found in the formation.

Age

Cooke (*in* Vaughan *et al.*, 1922, p. 61) reports the rudistid genus *Radiolites* from a limestone, which from his locality description is immediately north of the Rodeo Basalt and west along the strike of the limestones mapped by the writer at Las Mesetas. Rudistid fragments from three bioclastic limestone lenses within the formation have been identified by A.G. Fischer as belonging to the family Radiolitidae. Species belonging to this family are found throughout the Upper Cretaceous in the western hemisphere. Fossil localities where these rudistids have been found are 2806/21415, 2778/21415 and 2820/21407.

Planktonic foraminifera from sites 2798/21419 and 2837/21410 have been examined by E.A. Pessagno. His report is as follows:

Station 2798/21419:	an aphanitic limestone clast from an intraformational limestone conglomerate
CP-912:	*Globigerina* sp. *Globorotalia centralis* (?) *Globorotalia densa* (?) *Globorotalia* sp. (sharply keeled forms) Stratigraphic determination: Upper Paleocene to Upper Eocene, suggests Middle Eocene.
Station 2837/21410:	aphanitic limestone
CP-538:	*Globorotalia aragonensis* (?) *Globigerina* sp. (several species at least) *Globorotalia* sp. (keeled forms, several species at least) Stratigraphic determination: Upper Paleocene to Upper Eocene. Probably Lower to Middle Eocene.

The paleontological data offer two possibilities: (1) the rudistids are allochthonous, and the formation is Early Tertiary in age as suggested by the foraminifera; or (2) since all known occurrences of the rudistid-bearing bioclastic limestones are stratigraphically below the foraminifera-bearing limestones, the formation may range in age from Late Maestrichtian (upper limit of the rudistids) to Middle Eocene (probable age of the foraminifera).

The writer tentatively accepts the second possibility.

LOS CAGUELLES LIMESTONE BRECCIA

A small plate of sedimentary limestone breccia about one square km in areal extent rests unconformably on sub-greenschist facies rocks of the Duarte Formation at the settlement of Los Caguelles. The breccia is named for this settlement. At its northern limit its thickness is estimated as approximately 50 m; it apparently thins to a feather edge near the road at Los Caguelles.

The Los Caguelles Limestone Breccia is composed almost entirely of angular to subrounded fragments of limestone in a dusky red matrix composed of earthy hematite, clay (?) and calcite. Angular volcanic rocks constitute less than 10% of the clasts which range in size from 25 cm to less than 1 cm. The rock is poorly sorted, and although no stratification was observed, it may be bedded as no deep exposures were seen.

Limestone fragments show a wide range in color and texture. Colors include light grays, pinks and grayish reds. The majority are aphanitic and delicately laminated; others are microcoquinas. Clast shapes of many of the limestones have been modified by post-depositional solution. Some adjacent limestone clasts show marked interpenetration of one into the other.

Volcanic clasts include keratophyres and basic lavas similar to those of the sub-greenschist facies of the Duarte Formation. Many are extensively replaced by calcite, and in some of the basic lavas plagioclase laths are replaced by epidote. The latter replacement was observed in the sub-greenschist facies rocks where they are in fault contact with the greenschist facies of the Duarte Formation.

Age and Stratigraphic Relationships

A relative stratigraphic position for the Los Caguelles Limestone Breccia of post-Duarte Formation and pre-Tabera Group is indicated as clasts of the breccia have been found in the Inoa Conglomerate of the Tabera Group. W.A. Berggren (personal communication, 1961) identified *Globotruncana* sp. from one of the limestone clasts, which indicates that the limestone supplying the clasts was of Late Cretaceous age. Chronological age of the formation can be placed with certainty only within the limits post-Early Cretaceous, pre-Early

Oligocene.

Its stratigraphic relationship to the Magua Formation is not known; however, the folding which involved rocks of the Magua Formation also affected those of the Duarte Formation, but the Los Caguelles Limestone Breccia was apparently not involved in this deformation. On this basis the writer considers its stratigraphic position to be post-Magua Formation and pre-Tabera Group. Age suggested for the Los Caguelles Limestone Breccia is Late Eocene.

Origin

Matrix of the breccia probably originated as a terra rossa developed on the parent limestone. Source of the limestone clasts is not known, but because of their angularity, it must have been very close to the depositional site. Spatial relationship of the breccia to faults which place sub-greenschist facies rocks in contact with greenschist facies rocks of the Duarte Formation, and presence of epidotized volcanics in the breccia suggest that movement on either of these faults was the controlling factor in breccia genesis. The material may have been transported by a mass-wasting mechanism, such as a mud flow, or by short stream transport.

ROCKS OF UNCERTAIN STRATIGRAPHIC POSITION UNDERLYING OLIGOCENE ROCKS

Rocks of uncertain stratigraphic position are exposed in three separate areas along the Amina Fault. A fourth area, underlain by flow breccia, is exposed in the extreme eastern portion of the map area. A common feature of all of these rocks is that they underlie, or are in fault contact with, Oligocene rocks of the Tabera Group.

Flow Breccia Northwest of La Vega

Basalt or basaltic andesite is exposed in a large road cut about 7 km northwest of La Vega (northeastern extremity of Plate 1). These rocks have been described by Bowin (1966, p. 52), and the writer has no new evidence bearing on their age or stratigraphic position. Flow breccias are in fault contact with conglomerates which are probably equivalent to the Represa Conglomerate of the Tabera Group and are overlain to the north and east by Miocene sedimentary rocks.

The Las Matas Breccia

Rocks described herein as the Las Matas Breccia crop out in two separate areas along the Amina Fault west of San Jose de Las Matas. The two areas underlain by these rocks are prominent in the field in that they form bush-covered topographic highs in contrast to areas underlain by the Inoa Conglomerate. One area is approximately 2 km northwest of San Jose de Las Matas; the other is 3/4 km west of the bridge at the Rio Amina.

Rock color varies from dark brown through greenish-brown to apple green. The rocks are breccias in which fragments range in size from a fraction of a millimeter to over 4 cm in diameter. Fragments are enclosed by either a more finely granulated and lighter-colored matrix or by a network of veinlets. Thin sections examined indicate that fragments composing the breccia are texturally and mineralogically similar. Within fragments there is commonly a crudely developed microlamination contorted at the junction between fragments. Mineralogically, the fragments consist dominantly of quartz (maximum intercept diameter 0.04 mm) together with variable amounts of feldspar, pumpellyite and prehnite. Matrix between the fragments consists of variable proportions of the above-named minerals together with chlorite. Veins cutting these rocks consist of one or more of the minerals quartz, albite, prehnite and pumpellyite. Irregular replacement patches of calcite are present in some of the samples examined.

Brecciation of these tuffaceous siltstones is considered to be a tectonic feature related to movement on the Amina Fault. All that can be said concerning stratigraphic position of the tuffaceous siltstones of the Las Matas Breccia is that they are older than the

Early Oligocene Inoa Conglomerate because they occur as pebbles in the conglomerate. Further refinement of their stratigraphic position may come from a study of pebbles in the Magua Formation conglomerates. Las Matas rocks are readily identified in thin section, and should their occurrence in the conglomerates of the Magua Formation be established, a post-Duarte pre-Tertiary age would be indicated.

Rocks at El Rubio

A small area at the village of El Rubio is underlain by rocks which occur in the same structural setting as rocks of the Las Matas Breccia but differ from them in three respects: (1) they are spatially associated with serpentinite; (2) no volcanic siltstones are present; and (3) although they are brecciated on a small scale, as is the Las Matas Breccia, the El Rubio breccias vary in rock type from one outcrop to the next. Unmetamorphosed and metamorphosed rocks are present within short distances of one another in a seemingly haphazard fashion.

The rocks examined include the following: (1) a lava which resembles the sub-greenschist facies lavas of the Duarte Formation; (2) a basic hornfels consisting of hornblende, albite and quartz cut by veins of epidote and prehnite; (3) a pale greenish-white brecciated rock consisting largely of clouded plagioclase together with clinopyroxene, sphene and a trace of amphibole; and (4) altered diorite, which in all exposures found, is badly weathered. These rocks appear to be coarse-grained equivalents of the microdiorite type of inclusion commonly found in the serpentinites.

The first two rocks described may be from the Duarte Formation; their degree of metamorphism bears no relation to the nearest exposures of serpentinite. These rocks may represent rocks metamorphosed at depth and subsequently tectonically carried with the serpentinite to their present position.

TABERA GROUP

The name Tabera Formation was assigned by Cooke (*in* Vaughan *et al.*, 1922, pp. 67-69) for the sequence of blue-gray shale, sandstone, conglomerate, and minor limestone cropping out in the vicinity of Tabera (now Tavera) along the Rio Yaque del Norte. Cooke noted that the formation rests unconformably on epidiorite (metadiabase, of the Duarte Formation) and is overlain unconformably by the Lower Miocene Baitoa Formation. On the basis of fossils collected from these beds, Vaughan and Woodring (*in* Vaughan *et al.*, 1922) assigned a Middle Oligocene age to the formation. Bermudez (1949) has correlated rocks exposed in the Cordillera Septentrional with the Tabera Formation.

The writer has recognized three distinct mappable units along this section of the Rio Yaque and proposes that they be called formations of the Tabera Group. These formations are, as exposed along the Rio Yaque from south to north:

(1) a sequence of calcareous mudstones and sandstones called the Velazquitos Formation, the basal conglomerate of which rests unconformably on sub-greenschist facies rocks of the Duarte Formation;

(2) a thick sequence of conglomerate, here called the Represa Conglomerate, which is in fault contact with the Velazquitos Formation and is overlain with apparent conformity by:

(3) an upper sequence of sandstones and mudstones, here called the Janico Formation.

A fourth formation, the Inoa Conglomerate, composed dominantly of red boulder conglomerate is exposed in the western half of the map area. It is considered part of the Tabera Group and is probably correlative with the Represa Conglomerate. In the northwestern extremity of the map area a small area is underlain by organic limestone, herein referred to as the Moncion Limestone.

On paleontological evidence and structural considerations, the Represa and Inoa Conglomerates are believed to be the oldest formations of the group. The Velazquitos Formation is considered to be stratigraphically above the Inoa and Represa Conglomerates. These three formations are Early Oligocene in age (see below). Although the Janico Formation conformably overlies the Represa Conglomerate in the Rio Yaque, regional mapping indicates that the Janico Formation unconformably overlies all three of the Lower Oligocene formations of the group. The Janico Formation and the Moncion Limestone are Middle or possibly Late Oligocene in age.

The Inoa Conglomerate

The Inoa Conglomerate is composed dominantly of red boulder conglomerate. The name was originally proposed by Cucurullo (1961), who made brief mention of a red conglomerate exposed in the Rio Inoa in the vicinity of San Jose de Las Matas. The formation outcrops in a narrow structural graben over most of its length. To the north it is in fault contact with rocks of the Amina Formation (Fig. 6), and locally it is overlain unconformably by the Janico Formation. To the south it is in fault contact with the Magua Formation, the Duarte Formation and the Placetas Batholith. This southern fault contact can be traced from the extreme western part of the map area to the east of the settlement of Pedregal.

The area underlain by the Inoa Conglomerate is structurally complex. Neither top nor base of the formation was observed, and it is considered to have a minimum thickness of 600 m. The formation's most striking characteristic is its red color. In most outcrops the red pigment permeates the matrix and coats clasts so completely that the clasts have to be broken for petrographic identification. In the rarer non-red conglomerates the matrix is a gray sand. Transition from red to gray may be abrupt, and the line of separation coincides with bedding planes. In other exposures transition is more gradational; the red color may grade into gray up or down section, or the color change may be effected by several meters or tens of meters of alternating red and gray beds.

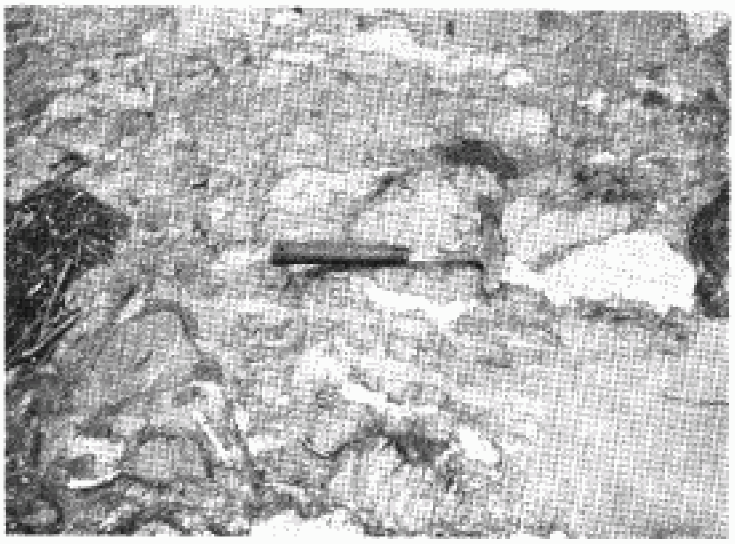


Figure 6. Inoa Conglomerate showing stretching of clasts near Amina Fault. Twenty-five meters south of first outcrop of the Amina Formation in the Rio Amina.

A number of distinct characteristics typify conglomerates of these two color types:

(1) in red conglomerates clasts have a greater average size and greater maximum size. Average boulder diameter is approximately 25 cm; boulders 60-90 cm across are not uncommon. In contrast, maximum observed clast diameters of gray conglomerates are approximately 25 cm with the average being considerably less;
(2) gray conglomerates are better sorted than red conglomerates;
(3) bedding is better defined in gray conglomerates; structural attitudes can be determined in red conglomerates only infrequently;
(4) within gray conglomerates interbedded sandstones are more common and have considerable horizontal persistence. Red sandstones within red conglomerates are rare and occur as lenses several meters or tens of meters in length;
(5) marine fossils have only been found in the gray facies;
(6) sand-sized material constitutes a greater percentage of the matrix in gray conglomerates, whereas material of small pebble or granule size, together with a hematitic "paste," constitutes most of the red conglomerate matrix.

Features which are common to both red and gray conglomerates are:

(1) similarity in degree of rounding of clasts. Most are well rounded.
(2) no noticeable change in relative proportions of clast types in the two types of conglomerate.

Conglomerate clasts are almost entirely of volcanic, metavolcanic and plutonic igneous rocks. Sedimentary rocks include chert and rare limestone. Clasts of boulder and large cobble size can usually be identified as derived from one of the formations south of the

Inoa Fault, i.e., the Duarte Formation and tonalite. Of the limestone clasts, few can be identified as derived from a particular formation. Limestones bearing rudistid fragments were observed and may be derived from the Magua Formation. Several clasts of the Los Caguelles Limestone Breccia have been found. Fine tuffaceous siltstone pebbles similar to those of the Las Matas Breccia have been examined in thin section. Perhaps the single most abundant clast in the pebble-size fraction is a hard, medium-to-dark gray, laminated fine-grained tuff. These types appear to be similar to the fine tuffs of the Tireo Formation (Bowin, 1966, p. 45). Lesser amounts of andesitic lava clasts bearing phenocrysts of plagioclase are also found, and these likewise may have been derived from the Tireo Formation.

Sandstones within the conglomerates are poorly sorted arenites characterized by abundant rock fragments and mineralogically immature mineral grains. Quartz and plagioclase typically constitute 50-60% of the mineral component of these rocks with the remainder made up of actinolite, hornblende, epidote, chlorite, muscovite, prehnite and opaque oxides. Rock fragments include rocks of the Duarte Formation, felsic tuffs, laminated tuffaceous siltstones, tuffaceous wackes and chert. In the red sandstones, the red pigment is a hematitic paste, which forms a selvage between mineral grains and more or less permeates the sedimentary rock fragments.

The Represa Conglomerate

The Represa Conglomerate is named for the dam (la represa) under construction in the Rio Yaque del Norte near the settlement of Los Ranchos de Tavera. At this place, rocks of the Represa Conglomerate are in fault contact with sandstones and mudstones of the Velazquitos Formation. North of the Tavera Fault, nearly continuous exposures of this formation can be seen in the gorge of the Rio Yaque almost to the village of Baitoa. Good exposures are also found south of Sabana Iglesia in the Rios Bao and Jaqua.

The base of the formation is not exposed; the lowermost exposed beds are in fault contact with the Velazquitos Formation. In the Rio Yaque the top of the formation is conformably overlain by sandstones and mudstones of the Janico Formation. South of Sabana Iglesia in the Rio Bao, the upper contact is not exposed, but in outcrops of each of the two formations, which are approximately 30 m apart, structural attitudes are markedly different. This structurally discordant relationship between the Represa Conglomerate and the Janico Formation continues westward to within a mile of the town of Janico, where both the conglomerate and the Tavera Fault are covered by younger rocks of the Janico Formation. A thickness of 2400 m is graphically calculated from exposures along the Rio Yaque del Norte.

The formation consists mainly of gray conglomerate and gray conglomeratic sandstone (Fig. 7). A few thin-bedded, calcareous mudstones constitute an insignificant part. An isolated lens of fossiliferous buff-colored limestone is exposed at the top of the formation south of Baitoa (3214/21361). This limestone has a transitional contact with the underlying conglomerate and on paleontological grounds is correlated with the limestone above the basal conglomerate of the Velazquitos Formation.

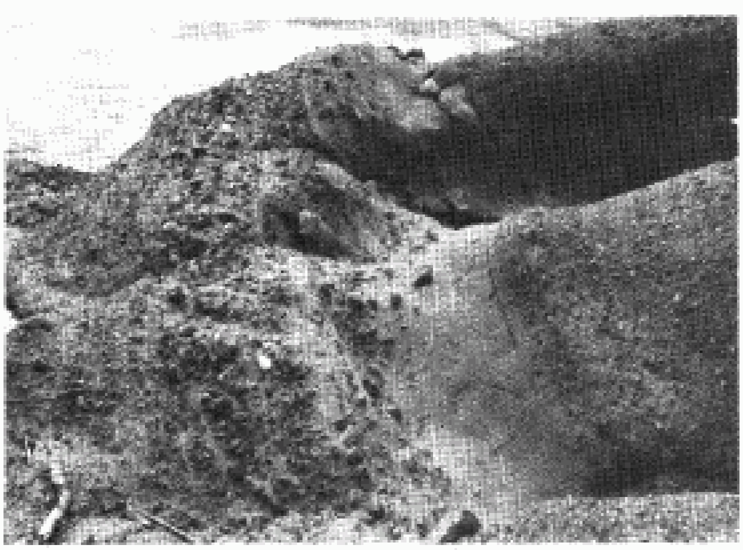


Figure 7. Represa Conglomerate approximately 1½ km north of the Tavera Fault in the Rio Yaque. Pebbly sandstone bed in center is 35 cm thick.

The most striking characteristic of the formation is its uniform appearance throughout its entire thickness; gray color, excellent bedding, and a large amount of sand matrix give the conglomerate a disrupted textural framework. Outcrops at the top of the section differ in no obvious respect from those near the base. There is no noticeable change in pebble size, relative proportions of pebble types, texture, or bedding characteristics.

Bedding occurs in several scales of thickness; commonly, beds with sharp upper and lower contacts are from 1½ to 10 m thick. Within one of these thick beds are secondary features, such as layers of coarse lithic sandstone, that define stratification. Some of these sandstones grade downward, or downward and upward, into conglomerate, in the former case exhibiting crudely developed graded bedding. Along river valleys individual beds of sandstone less than 30 cm thick have been traced along strike for at least 65 m.

The majority of the clasts fall into the size range between 1 and 12 cm. A contrasting feature of the Represa Conglomerate, as compared with the basal conglomerate of the Velazquitos Formation or the gray conglomerates of the Inoa Conglomerate, is the greater proportion of sand- and granule-size matrix. Although in some layers pebbles are densely packed and are in mutual contact, most of the conglomerate is best described as conglomeratic sandstone. The sandstone matrix is locally calcareous and bears marine fossils (orbitoidal foraminifera and other unidentifiable types). Rarely are the clasts bonded by a limestone matrix relatively free of terrigenous sand.

The clasts are almost entirely of volcanic and metavolcanic rocks. Tonalite, hornblendite, and rocks of the Duarte Formation have all been observed. By far the most abundant clasts are hard black-to-gray and yellow-green volcanic rocks. As in the Inoa Conglomerate, the source of these types may have been the Tireo Formation.

The Velazquitos Formation

The Velazquitos Formation is named for an arroyo which enters the Rio Yaque del Norte, but it is well exposed also in the Rios Yaque, Guanajuma, Baiguaque, Jaqua and Bao. The base of the formation rests unconformably on rocks of the Duarte Formation; the top of the formation is not observed. To the north, the formation is in fault contact with the Represa Conglomerate. Because of intense disharmonic folding, no estimate of thickness is made.

The base is conglomerate, varying from a few meters to over 60 m in thickness and dipping with low to moderate angles off the older rocks of the Duarte Formation. Where it is thickest, it is composed of subangular to subrounded boulders up to 1 m in diameter set in a matrix of subangular cobbles, pebbles and sandstone. Where the basal conglomerate is thin, as in the Rio Guanajuma, it is composed of smaller pebbles set in a calcareous sandy matrix. In most places it is conformably overlain by an organic limestone that forms a more or less continuous ridge from east of the Rio Baiguaque to the eastern end of the map area, where the base of the Tabera Group abuts against a prong of the Loma Caribe serpentinized peridotite. In the Rio Yaque it is approximately 15 m thick, and probably nowhere does it exceed 30 m in thickness. The limestone, which is olive-gray to yellowish-gray in color, contains abundant algae and orbitoidal foraminifera. West of the Rio Jagua north of Los Caguelles, the limestone is absent, and its place is taken by a calcareous conglomeratic sandstone about 10 m thick which is made up of at least 50% orbitoidal foraminifera.

The basal conglomerate and limestone are conformably overlain by a monotonous sequence of dark gray rocks in which calcareous mudstones and fine- to medium-grained sandstone are the dominant types. Coarse sandstones are subordinate, forming about 30% of the thickness. Individual beds of pebble conglomerate and pebbly sandstones are rare. Mudstones and fine- to medium-grained sandstones generally occur in beds 3-10 cm thick. Coarse sandstone beds vary between 30 and 60 cm, and pebble conglomerates and pebbly sandstones occur in beds approximately 1 m thick. Cross-bedding and ripple marks were not seen. The coarse sandstones are not obviously graded; where interbedded with mudstones, upper and lower contacts are sharp. A few of the fine-grained sandstones and silty mudstones are graded, however, as are some of the pebbly sandstones that rest on scoured surfaces on underlying mudstone or sandstone. Plant debris and unidentifiable leaf fragements are not uncommon on bedding planes, and thin seams of coal were found in one calcareous sandstone bed.

Although most of the sandstones appear to be graywackes in hand specimen, thin section examination shows that none of them have 10% argillaceous matrix, and therefore they are arenites rather than wackes. They are all characterized by a high percentage of angular, poorly sorted, unstable mineral and rock fragments. Calcite is the cement. The mudstones are calcareous and generally lack a bedding plane fissility in that they tend to break into small irregular sharp chips. All mudstones contain a moderate amount of very fine sand-and silt-sized grains of quartz and other minerals typical of the sandstones. The mud matrix consists of clay, carbonaceous matter, turbid calcite and small foraminifera. Two samples examined by x-ray diffraction showed that montmorillonite and chlorite are the principal clay minerals.

The Janico Formation

Excellent exposures of the Janico Formation occur near the town of Janico along the road to Santiago and along the road between Janico and San Jose de Las Matas. Readily accessible exposures are also present in the Rio Bao at Sabana Iglesia and in the Rio Yaque near Baitoa. The formation unconformably overlies the Inoa Conglomerate and the Represa Conglomerate as far east as Sabana Iglesia. In the Rio Yaque del Norte it rests conformably on the Represa Conglomerate and is unconformably overlain by the Lower Miocene Cercado Formation. From exposures in the Rio Yaque, its thickness is estimated at 760 m.

The formation consists of calcareous sandstones and mudstones together with minor amounts of pebble conglomerate. The sandstones and mudstones are medium-light gray where fresh ("blue-gray shales" of Cooke *in* Vaughan *et al.*, 1922) and are yellowish when weathered. Thin and very persistent bedding is typical of the formation. Medium- and thick-bedded sandstones are restricted to the lower part of the section. The sandstones are well-to-moderately well indurated and stand out as ribs between the mudstones, which crumble into conchoidal fragments. Many of the sandstones and mudstones have laminations of coarser sand or fine silt, which in many beds are disrupted by worm burrows. Graded bedding is present in only a few sandstones and is never conspicuous in outcrop. Graded laminae in the mudstones have been seen but they, too, are infrequent. Irregular polygonal fractures, which look like mudcracks, are present on some bedding planes of the sandstones. Abundance of pelagic foraminifera in the interlayered mudstones makes it unlikely, however, that these represent true dessication features formed by subaerial exposure. Fragmentary plant leaf impressions are present in some sandstones and are present in abundance within the mudstones.

Lighter color of the sandstones, as compared to those of the Velazquitos Formation, is reflected in their mineral composition. Several significant differences are: (1) absence of pyroxene and a considerably smaller proportion of other ferromagnesian minerals; (2) the more weathered nature of rock fragments with only the more resistant types remaining; and (3) a very large amount of calcite cement and matrix. In many sandstones calcite forms 40% or more of the rock, and few of the detrital silicate grains are in mutual contact. Presence of calcareous foraminifera indicates that the rocks originated by intermixing of terrigenous detritus with carbonate mud and sand in the depositional basin. In some sandstones radiolaria are completely replaced by calcite.

All of the mudstones are calcareous, and many which lack silt laminations could properly be called claystones. Because of their poor induration, only one mudstone was studied in thin section and showed the only fossils to be pelagic foraminifera and calcite-replaced radiolaria. Foraminifera were separated from another claystone and were entirely pelagic types (W.A. Berggren, personal communication, 1961). Four claystones were examined by x-ray diffraction; montmorillonite and chlorite are present in all, and a trace of illite is present in one.

The conglomerates are of two types. One occurs as isolated thick beds (1-5 m thick), or in a series of thick beds aggregating tens of meters in thickness. These contain pebble- and small cobble-sized clasts and have a large amount of sandy matrix. They differ in no respect from the rocks of the Represa Conglomerate except for concentrations of coral debris and modules of algal limestone on bedding planes. This type of conglomerate has only been found in the Rio Yaque at Baitoa and east of Sabana Iglesia in the Rio Bao. These two occurrences probably represent the same beds. The second conglomerate type occurs in much thinner beds (4-60 cm thick) and has sharp contacts with adjoining sandstone and claystone beds. Beds of this type have moderately well size-sorted rounded pebbles up to 2 cm in diameter.

The Moncion Limestone

A prominant cliff of limestone is exposed 3-4 km west-northwest of the town of Moncion. At Gurabo the limestone rests unconformably on the Amina Formation and is unconformably overlain by the Early Miocene Cercado Formation. Thickness of the Moncion Limestone was not measured, but it probably does not exceed 45 m.

The limestone is a yellowish-gray, hard, organic limestone. Where stratification is seen, it is in thick, ill-defined beds. Algae and large orbitoidal foraminifera are conspicuous components of the rock. Thin section examination shows that algae, coral fragments, millipores, and large and small benthonic foraminifera compose from 50 to as much as 80% of the limestone. The limestone matrix shows irregular distribution of several textural types of calcite, which suggests disturbance by burrowing organisms.

Paleontology and Age of the Tabera Group

Paleontology of the Represa Conglomerate

An upper limit is placed on the age of the Represa Conglomerate from the fauna of the limestone at the top of the conglomerate south of Baitoa. The following is an excerpt from the report of W.S. Cole (personal communication, 1962) on specimen CP-689 collected at station 3214/21361: "The dominant, large specimens are *Lepidocyclina* (*Eulepidina*) *undosa* Cushman. There are rather numerous sections of *Camerina dia* (Cole and Ponton), and rarer sections of *Lepidocyclina* (*Lepidocyclina*) *canellei* Lemoine and R. Douville. In addition, there may be present *Lepidocyclina* (*Eulepidina*) *yurnagunensis* Cushman, but I cannot be absolutely certain. The association is typical of certain parts of the Meson Formation of Mexico and the Suwannee Limestone of Florida. In fact, I would place it equal to the *Streblus mexicanus mecatepecensis* zone of the Suwannee, as I observed some sections I am certain represent this species."

Paleontology of the Inoa Conglomerate

The following material was collected from gray sandstones of the Inoa Conglomerate. The large foraminifera were determined by W.S. Cole and the single coral by J.W. Wells:

Station 3076/21367:	coarse gray sandstone bed within conglomerate
CP-315:	*Lepidocyclina* (*Eulepidina*) *undosa* Cushman (fragments scarce) *Operculina dia* (Cole and Ponton)
Station 2883/21401:	coarse gray fossiliferous sandstones and pebbly sandstones within conglomerate
CP-745:	*Heterostegina antillea* Cushman *Lepidocyclina* (*Eulepidina*) *undosa* Cushman
CP-747:	*Lepidocyclina* (*Eulepidina*) *giraudi* R. Douville *Lepidocyclina* (*Eulepidina*) *undosa* Cushman *Camerina dia* (Cole and Ponton)
Station 2796/21452:	calcareous gray sandstone
CP-910:	*Lepidocyclina* (*Eulepidina*) *undosa* Cushman *Lepidocyclina* (*Eulepidina*) *yurnagunensis* Cushman *Heterostegina antillea* Cushman
CP-909:	*Leptoria* sp. aff. *L. spenceri* Vaughan (coral). Olig., Cuba

Paleontology of the Velazquitos Formation

W.S. Cole (personal communication, 1960, 1961) has determined a number of large foraminifera from samples collected by the writer from the base of the Velazquitos Formation:

Station 3236/21285:	light gray-to-buff algal limestone above the basal conglomerate
CP-463a:	*Operculina dia* (Cole and Ponton) *Lepidocyclina* (*Eulepidina*) *undosa* Cushman
CP-463b:	same as CP-463a but also bears *Lepidocyclina* (*Lepidocyclina*) *giraudi*

Station 3102/21339:	fossiliferous sandstone at the top of the basal conglomerate
CP-634:	*Camerina dia* (Cole and Ponton) *Lepidocyclina* (*Eulepidina*) *undosa* Cushman
Station 3079/21345:	fossiliferous sandstone
CP-404:	*Operculina dia* (Cole and Ponton) *Lepidocyclina* (*Eulepidina*) *undosa* Cushman
CP-405a:	*Operculina dia* (Cole and Ponton) *Lepidocyclina* (*Lepidocyclina*) *giraudi* *Lepidocyclina* (*Eulepidina*) *undosa* Cushman
CP-405b:	*Operculina dia* (Cole and Ponton) *Lepidocyclina* (*Eulepidina*) *yurnagunensis* Cushman *Lepidocyclina* (*Eulepidina*) *undosa* Cushman

Age of the Velazquitos Formation, Inoa Conglomerate and La Represa Conglomerate

Regarding the age of the Velazquitos Formation and the Inoa Conglomerate, Cole writes (personal communication, 1961) concerning the above fossil determinations: "The sections all seem to represent my *Lepidocyclina* subzone of the Oligocene *Eulepidina* zone, therefore, Lower Oligocene as I recognize it at present. There is no indication of the *Miogypsina* subzone of the *Eulepidina* zone which I consider to be Upper Oligocene. However, the faunas are small, and therefore characteristic species of the upper subzone are not present. The species present all range throughout the *Eulepidina* zone; therefore, I am basing my conclusion in part on negative evidence."

In earlier correspondence he writes: "An approximate correlation would be with parts of the Meson Formation of Mexico, the Suwannee Limestone of Florida and the Bohio Formation of Panama."

All four species of foraminifera from the limestone at the top of the Represa Conglomerate are present in the basal limestone of the Velazquitos Formation. These foraminifera indicate an upper age limit of Early Oligocene for the Represa Conglomerate.

Paleontology and Age of the Janico Formation

Bermudez (1949) studied foraminifera from three localities (labeled as his sites H15161, H15154 and H15179) within the Janico Formation of this study. These three localities yielded a total of nine species from which Bermudez estimated a Middle Oligocene age.

W.A. Berggren (personal communication, 1961) identified the following species from a mudstone, CP-620, collected at 3076/21382:

Globigerina ciperoensis augustiumbilicata Bolli
Globigerina globularis Roemer
Globigerina cf. *triloculuris* d'Orbigny
Age: *Globigerina ciperoensis augustiumbilicata* and *Glogigerina trilocularis* are present in the Oligocene portion of the Cipero Formation of Trinidad (Bolli, 1957).

J.W. Wells identified the following corals collected by the writer from a coral-rich bed on the upper bedding plane of a conglomerate bed at Baitoa (3205/21378). Wells writes (personal communication, 1961) with regard to these corals: "The corals you sent are in a sad state of preservation, and I can give only approximate identifications of these reef corals as follows:

CP-722, CP-723:	*Montastrea* sp. cf. *M. canalis* Vaughan. Upper Oligocene, Anguilla, C.Z.
CP-724:	*Siderastrea* sp. cf. *S. pariana* (Duncan). Oligocene, Trinidad. Also much like *S. radians* (Pallas). Pliocene to Recent."

The age ot the Janico Formation is Middle or possibly Late Oligocene.

Paleontology and Age of the Moncion Formation

Thin sections of samples from two localities were examined by P.J. Bermudez and W.S. Cole. Those with concentrations of small foraminifera are reported by Bermudez as follows:

"Station 2680/21507:

CP-973: *Carpenteria* sp.
Amphistegina sp.
Rotalia mexicana mecatepecensis Nuttal
Algas calcareas
Fragmentos de corales
Fosiles sin determinar

Station 2660/21507:

CP-975: *Amphistegina* sp.
Carpenteria sp. (fragmentos)
Planorbulinella sp. (fragmentos)
Rotalia mexicana mecatepecensis Nuttal
Algas calcareas
Espinas de equinoideos (*Cidaris* sp.)
Fragmentos de corales

Station 2699/21491:

CP-978: *Amphistegina* sp.
Carpenteria sp.
Heterostegina israelskyi Gravell y Hanna
Lepidocyclina sp. cf. *L. undosa* Cushman
Rotalia mexicana mecatepecensis Nuttal
Algas calcareas
Fragmentos de foraminiferos

Station 2699/21491:

CP-980: *Amphistegina* sp.
Carpenteria sp. (fragmentos)
Globigerina sp.
Heterostegina israelskyi Gravell y Hanna
Gypsina sp.
Lepidocyclina sp. of *L. favosa* Cushman"

Bermudez makes the following comment regarding age of the Moncion Limestone: "Estas calizas se extienden a lo largo del flanco sur de la Cordillera Septentrional y se cree que pueden tener una edad de Eocene superior a Oligoceno medio, pudiendose correlacionar con las calizas que afloran en la Sierra de Neiba. El material estudiado es muy fosilifero y contiene abundantes ejemplares de *Rotalia mexicana mecatepecensis* Nuttal, *Heterostegina israelskyi* Gravell y Hanna y especies grandes de *Lepidocyclina*, los que indican una edad probablemente de Oligocene medio."

W.S. Cole examined the large foraminifera and reports the following (personal communication, 1961):

Station 2699/21491:

CP-980: *Lepidocyclina* (*Eulepidina*) *undosa* Cushman (abundant)
Lepidocyclina (*Eulepidina*) *tournoueri* Lem and R. Douville (frequent)
Heterostegina antillea Cushman (rare)

Cole makes the following comment on the age: "The age indicated is Upper Oligocene. Many of the specimens are broken and abraided. This might indicate transportation, but seemingly there are no foreign elements in the fauna."

The age of the Moncion Limestone can be considered, therefore, as either Middle Oligocene or Late Oligocene. The Moncion Limestone may correlate with the Janico Formation.

Environment of Deposition and Structural History of the Tabera Group

Because the Inoa Conglomerate, the Represa Conglomerate and the Velazquitos Formation have been shown to be of the same age, within the limits of paleontological data, and no unconformity is recognized among these formations, they will be treated together.

During the course of field investigation, the writer made some observations on competence of rivers which flow across the contact of the Oligocene formations with older rocks to the south. With present-day relief these rivers have competency to transport boulders of quartz diorite and amphibolite (up to 2 m in diameter) approximately 1 km and boulders (up to 60 cm in diameter) at least 8 km from the closest source of these rock types. Thus, present-day relief is more than adequate to supply boulders of the size found in the Inoa Conglomerate.

Differences in texture and bedding of the red and gray facies of the Inoa Conglomerate indicate that depositional conditions were not uniform. Since marine fossils have been found only in the gray facies, constrasting differences are assumed to be related to subaerial deposition of the red facies and marine deposition of the gray facies. The Represa Conglomerate is marine and has a disrupted textural framework and crudely developed graded bedding, which suggests deposition below wave base. Rocks of the Velazquitos Formation are marine and, with the exception of the basal conglomerate and basal limestone, appear to have been deposited below wave base, as is suggested by local presence of graded bedding and absence of shallow-water sedimentary features. Vaughan (1933) considers 50 m as the probable maximum depth of water in which the orbitoidal foraminifera occurring in all three formations lived. These foraminifera indicate a reliable maximum depth of deposition for the gray facies of the Inoa Conglomerate and the basal beds of the Velazquitos Formation. Their occurrence in the coarse sandstones and pebble conglomerates and absence in the mudstones of the Velazquitos Formation suggest that they may have been transported to greater depths during deposition. Where they do occur in the Represa Conglomerate, they are always fragmentary and may have been transported to depths greater than 50 m.

It is to be noted (Plate 1) that the Inoa Conglomerate is in fault contact with older rocks to the south, whereas the Velazquitos Formation lies unconformably on the older rocks of the Duarte Formation. Both the Inoa Fault and the basal sedimentary contact of the Velazquitos Formation are very straight features and are along strike of one another. This suggests that the surface trace of the unconformable surface between the Velazquitos and Duarte Formations may represent a recessed fault scarp. It is proposed that the Inoa Fault and its buried extension occur a short distance north of the present basal contact of the Velazquitos Formation and that the fault was active during the time of deposition of the Inoa and Represa Conglomerates.

Accordingly, it is suggested that the western half of the map area in Early Oligocene time was a fairly mountainous area similar to that existing today and bounded on the north by an active Inoa Fault. North of the fault, streams deposited their loads, part of which was periodically reworked by landward transgressions of the shoreline. Farther east, similar conglomerates were deposited and abraded to finer sizes along the shoreline. When fault movement ceased, the basal conglomerate of the Velazquitos Formation was deposited, followed by the basal limestone of the Velazquitos Formation and the limestone on top of the Represa Conglomerate south of Baitoa. The sea then transgressed over the fault and some unknown amount of rugged source area to the south. The remaining source area continued to supply an abundance of mineralogically immature detritus, which, in part at least, was carried below wave base by turbidity currents forming the sandstones and mudstones of the Velazquitos Formation.

Lower Oligocene rocks were then folded, with more incompetent sandstones and mudstones of the Velazquitos Formation folding disharmonically over the more competent Represa Conglomerate beneath. The Represa Conglomerate was upfaulted along the Tavera Fault, and at this time vertical movement probably began along the Amina Fault, enclosing the Inoa Conglomerate in a structural graben. Erosion continued, followed by subsidence in Middle Oligocene time.

The mineralogically more mature sands of the Janico Formation indicate that by Middle Oligocene time the source area was reduced somewhat in relief. Presence of corals and abundance of benthonic foraminifera, carbonate mud and sand indicate that terrigenous sands accumulated on a shallow marine shelf; claystones with their deeper-water fauna suggest pelagic sedimentation. Regular repetition of alternating claystones and sandstones is best explained by normal pelagic sedimentation of relatively deep-water marine clays, interrupted periodically by turbidity current influxes of calcareous sands.

In contrast, the broken and abraded nature of orbitoidal foraminifera from the Middle-to-Late Oligocene Moncion Limestone indicates that the depositional basin was shallow and the water fairly turbulent in the western part of the map area.

MIOCENE SEDIMENTARY ROCKS

A thick, apparently conformable sequence of Lower, Middle and Upper Miocene sedimentary rocks underlies a 25-45-km wide belt between the Cordillera Central and the Cordillera Septentrional. These rocks of the Cibao region have been studied by a number of workers attracted by their rich fossil faunas (Moore, 1849; Heneken, 1853; Maury, 1917; Cooke *in* Vaughan *et al.*, 1922; and Bermudez, 1949). Only the lowermost Miocene beds, those of the Cercado Formation and its Bulla Conglomerate Member, are exposed in the map area of this study.

The Cercado Formation consists of medium-to-thick-bedded calcareous sandstones. The base of the formation is conglomeratic, and where these conglomerates have appreciable thickness, they have been mapped as the Bulla Conglomerate. The Cercado Formation, or its basal member, rests unconformably on the Duarte and Amina Formations and on the Oligocene rocks of the Tabera Group. The Bulla Conglomerate has a thickness of approximately 120 m at the type locality (Cooke *in* Vaughan *et al.*, 1922), and Bermudez (1949, p. 14) gives 580 m as the thickness of the Cercado Formation in the Rio Mao.

The Bulla Conglomerate consists of lithic conglomerate composed of well-rounded to subrounded boulders, cobbles and pebbles in a rusty-colored sand or grit matrix. Clast types in order of decreasing abundance are tonalite, greenstones, felsic tuffs, and vein quartz. Where exposed in road cuts, most of the tonalite and greenstone clasts are badly weathered and crumble with one blow of the pick. The sand matrix is semi-consolidated and locally calcareous. Cross-bedded lenses occur sporadically. The conglomerate is also locally calcareous and fossiliferous, e.g., at Baitoa.

Calcareous sandstones of the Cercado Formation overlie the basal conglomerates with either a transitional contact or an abrupt conformable contact. These thick-bedded sandstones range in color from light yellowish-gray to greenish-gray. Cross bedding is locally seen and is particularly well developed in exposures along the road between El Rubio and Bulla. Probably the best lithological criteria in distinguishing the Cercado Formation from the younger Miocene formations of the Cibao region are the presence of discoidal, well indurated masses of sandstone or pockets of coquina averaging 1½ m in diameter and 30 cm in thickness. They form discontinuous lenses aligned parallel to the bedding and are very conspicuous where they occur within more friable and less calcareous sandstone. The coquinas are composed of pelecypod and gastropod shells together with their internal and external molds. Bryozoa, corals and echinoderms are less abundant. These types of shallow-water fossils, together with rare well preserved plant leaves, are found in the less calcareous sandstones but in much less abundance.

Local presence of marine fossils in the Bulla Conglomerate indicates that part of this member is marine. It appears likely that this conglomerate represents a strand-line type of deposit, in part marine and in part fluvial in origin. Thick and locally cross-bedded sandstones of the Cercado Formation indicate deposition in a high energy environment. Abundance of molluscs, including many relatively thick-shelled types, indicates very shallow marine depositional conditions.

INTRUSIVE ROCKS

Serpentinized Peridotite

Serpentinites are abundant only in the eastern part of the map area where they occur as bodies satellitic to the Loma Caribe serpentinized peridotite (Bowin, 1966, pp. 58-62). These satellitic bodies occur within the eastern sub-greenschist facies of the Duarte Formation, or within or in contact with, Lower Oligocene rocks of the Tabera Group. Only one occurrence of serpentinite is known in the western part of the map area; this body, less than 100 m in outcrop width, is at the village of El Rubio.

Most of Bowin's (1966) observations pertaining to the Loma Caribe mass also apply to smaller bodies within the present map area. These bodies are virtually totally serpentinized and in outcrop display a multiplicity of smooth irregularly-trending joints and fracture surfaces which are blue or green in color. On freshly broken surfaces the serpentinite is greenish-black or black with a resinous lustre. Orthopyroxene or bastite pseudomorphs of orthopyroxene are the only identifiable relict minerals seen in hand specimens.

The majority of the rocks studied in thin section are completely serpentinized with chrysotile as the dominant serpentine mineral. Bastite pseudomorphs of orthopyroxene constitute as much as 25% of some rocks. In unsheared specimens mesh structure, outlined by the concentration of magnetite in polygonal patterns, is well preserved. Chromite, though much less abundant than magnetite, occurs in larger rounded-to-irregular-shaped grains. A small amount of relict olivine and orthopyroxene was present in only one of the thin sections examined. Absence of plagioclase and clinopyroxene suggests that the original rocks were dunite and harzburgite.

Numerous inclusions of altered rocks within the serpentinites can be grouped into two end-member types, the most abundant of which is a hard, medium-to-dark gray, fine-to-medium-grained massive rock. Coarser varieties have the appearance of microdiorite or diabase; finer-grained ones have the texture of hornfels. The second type of inclusions is aphanitic, dense, white-to-cream-colored rodingites.

The microdiorite type occurs as blocks ranging from a fraction of a meter to tens of meters across. Edges and corners of these blocks may be either rounded or angular. In thin section the least altered of the microdiorite type shows an igneous texture of clouded laths of plagioclase (medium oligoclase to sodic andesine) and hornblende. The hornblende is distinctive in that parts of individual crystals have a reddish-brown color which grades into pale or medium green. The more intensely altered specimens have a hornfelsic texture and consist of an aggregate of pale green amphibole with brownish tinge and prehnite. As in the less altered specimens, ilmenite, sphene and leucoxene are present in accessory amounts.

Blocks of rodingite have been found in only one of the serpentinite bodies (exclusive of the Loma Caribe serpentinized peridotite). They occur in the small serpentinite mass exposed in the Rio Yaque south of the Tabera Group-Duarte Formation contact. A sample of one of these blocks was examined in thin section and by x-ray diffraction and shows the rock to consist of anhedral, turbid hydrogarnet (a_o=11.956Å±0.003Å, N=1.685±0.003), clinopyroxene, vesuvianite, chlorite, and a colorless mineral with very low birefringence and mean R.I. of 1.602. Veins of euhedral salite ($2V_z$=58°, Ny=1.690) and minor chlorite cut the rock. A dark reaction rim surrounding the block consists of serpentine and 14° A° chlorite.

Bowin (1966, p. 60) has described rocks which are intermediate in mineralogy between the microdiorite types and the rodingite described above. The writer concurs with Bowin (1966) that the most probable explanation for these inclusions is that they represent variably altered dike rocks which were brecciated during tectonic movement of the serpentinized peridotite.

Because of general absence of contact metamorphic effects between country rocks and serpentinized peridotites (Bowin, 1966, pp. 61-62, and observations of the writer), the serpentinized peridotites are not considered to be intrusive rocks in the magmatic sense. Evidence gathered from field geology, marine geology and geophysics, and experimental petrology over the last decade indicates that the serpentinized peridotites in the Greater Antilles most probably represent upper mantle rocks which have reached the present surface as solids (Hess, 1966). The serpentinites are interpreted as basement and appear at the base of the stratigraphic sequence in Figure 1, even though they have been tectonically transported upward as late in time as Early Oligocene.

Diabase and Metadiabase

Only two small bodies of diabase and metadiabase have been mapped; float of diabase and metadiabase was found in other areas underlain by the Duarte Formation, but the scale of field mapping did not permit delimitation of these intrusive bodies.

One of the mapped units is a fine-to-medium-grained metadiabase that occurs as a sill within bedded cherts of the Duarte Formation south of Pinalito. Original igneous texture of the rock has largely been obliterated. The rock consists of a granoblastic aggregate of pale green amphibole, albite, and epidote, with lesser amounts of chlorite and leucoxene. The greenschist facies mineralogy implies that the sill was emplaced prior to the regional metamorphism of the Duarte Formation.

The second of the mapped units is exposed in the eastern part of the map area southwest of the settlement of Bayacanes. This intrusive body is in contact with sub-greenschist facies rocks of the Duarte Formation and the Loma Caribe serpentinized peridotite. It is fault-bounded on two sides by Lower Oligocene rocks of the Tabera Group. In contrast with the sill south of Pinalito, the diabase southwest of Bayacanes still retains an igneous texture, especially in exposures distant from contacts with other rock units. A sample collected near the center of the intrusive shows augite interstitial to, and ophitically enclosing, plagioclase laths. Plagioclase occurs in laths between 2 and 0.5 mm in length and forms approximately 55% of the rock. The plagioclase is partially replaced by chlorite, prehnite and epidote. Actinolite and chlorite partially replace augite and also occur interstitially to plagioclase. Accessory amounts of quartz and ilmenite are also present. Samples collected close to fault contacts are finer-grained and resemble hornfels in hand specimens. A thin section of one of these samples shows complete reconstitution to albite-amphibole rocks cut by abundant veinlets of prehnite. Degree of alteration of the intrusive southwest of Bayacanes is similar to that in lavas of the sub-greenschist facies of the Duarte Formation. This intrusive and the sill south of Pinalito therefore are thought to have been emplaced prior to the time of metamorphism of the Duarte Formation.

Tonalite

Tonalite plutons ranging in size from small bodies a fraction of a square km to bodies of batholithic dimensions underlie large areas of central Hispaniola. In general, these areas are less rugged and of lower elevation than the surrounding country rocks. Topographic change does not follow outlines of the plutons in detail, however; many contacts occur part way up steeper slopes which enclose low-lying areas underlain by igneous rocks. Plutonic rocks weather more rapidly than enclosing volcanic and metavolcanic rocks and produce a quartzose granular soil. Such soil is a valuable aid in mapping plutonic outlines but so blankets the area that it is difficult to obtain fresh samples for petrographic examination and to observe internal structure and contact relationships.

The writer uses the terms 'tonalite' and 'quartz diorite' synonymously. Classification is that of Peterson (1961), in which quartz diorite is defined as a granitoid rock in which potassium feldspar forms 1/10 or less of the feldspar and quartz constitutes more than 10% of the total rock. The two types of tonalites, namely foliated and unfoliated, mapped by Bowin (1966, pp. 66-70) in the central Dominican Republic have been recognized in the present area. Because hornblende is the characteristic varietal mineral of the unfoliated tonalites, these rocks are called hornblende tonalites in this report. Foliated tonalites typically have a lower color index and are herein called leucotonalites.

Laboratory study of these rocks was based on 35 thin sections. The sections were stained for both potassium feldspar and plagioclase, following the method of Bailey and Stevens (1960), and modal analyses (2000 point counts) were made with a mechanical point counter. Results of modal analyses of leucotonalite samples are given in Table 2, and those of samples from the Placetas Batholith, considered to be typical of all the hornblende tonalites, in Table 3. Plagioclase compositions were determined by index of refraction measurements of feldspar powder concentrates from crushed portions of the samples.

Granitic rocks of the circum-Caribbean region are characterized by low potassium contents. In over 50 thin sections of acid plutonic rocks from the Dominican Republic studied by Bowin (1966) and this writer, the maximum amount of potash feldspar is 5.1% by volume. Quartz diorites are the prevalent type of granitic rock west of "the quartz diorite line" of western North America (Moore *et al.*, 1961). This observation has been taken as evidence

Sample No.	Pc	Qtz	Hb	Op	Chl	Epi	Kf	Non-op Acc	Bi	Pc Comp.	Mus
CP-447	53.0	32.3	3.4	1.5	5.3	3.9	---	0.4	0.2	An 40-43	---
CP-873	48.3	39.6	---	---	6.3	5.8	---	---	---	---	---
CP-869	40.1	31.8	0.1	---	8.9	18.7	---	0.1	---	An 7	0.3
CP-671	37.6	35.5	9.1	---	7.6	10.2	---	---	---	An 6	---
CP-642	38.8	35.6	5.0	0.1	11.2	7.8	1.0	0.2	0.3	An 10	---
CP-420	42.8	43.8	---	0.1	3.2	6.5	0.6	0.1	2.9	An 8	---
CP-628	41.9	40.0	---	---	0.4	7.4	0.6	---	8.7	An 14	1.0
CP-874	39.9	36.8	---	---	11.6	11.5	0.1	0.1	---	An 12	---

Pc = plagioclase
Qtz = quartz
Hb = hornblende
Op = opaque
Chl = chlorite
Epi = epidote
Kf = K feldspar
Non-op Acc = non-opaque accessory
Bi = biotite
Mus = muscovite

Table 2. Modal analyses of leucontonalites (values are in volume percent).

for a thin continental crust during generation of these rocks.

Leucotonalite

Plutons of leucotonalite occur only in the greenschist facies of the Duarte Formation. Contacts of these plutons are, in general, concordant with the enclosing schists. At the contact between Duarte amphibolites and the tonalites, veins of gneissoid tonalite occur as injections between foliation planes of the amphibolites. Characteristically, the leucotonalites have a strongly developed marginal foliation, which is parallel to the contact with the host rocks. Where foliation persists into the central portion of the plutons, it commonly shows rapid changes in strike over tens or hundreds of meters.

Leucotonalites typically have a lower color index than hornblende tonalites and have affinities with trondhjemites. Quartz is more abundant, and hornblende and opaque oxides are present only locally. Chlorite, epidote, muscovite and biotite are typical varietal minerals. Accessory minerals are Fe-Ti oxides, apatite and sphene.

Textures of these rocks range from medium-grained equigranular to those in which individual quartz and plagioclase grains are joined, making lens-shaped clots approaching 1 cm in longest dimension. Outlines of the plagioclase range from subhedral to anhedral; some show the effects of granulation, and in one slide examined twin lamellae are bent. Quartz commonly shows mutually sutured contacts and in some slides shows strong undulatory extinction. Reference to Table 2 shows that chlorite and epidote are constant varietal minerals of these rocks. Chlorite and some epidote, together with hornblende or biotite where these minerals are present, are concentrated in discontinuous trains between quartz and plagioclase grains. Parallel disposition of micaceous minerals and textural features of the quartz and plagioclase are considered to be the result of differential movement during forceful emplacement of these rocks.

Hornblende Tonalite

Hornblende tonalites intrude the greenschist and sub-greenschist facies of the Duarte Formation. In the central Dominican Republic they intrude the Tireo, Los Ranchos and Duarte Formations (Bowin, 1966, Plate 1).

Modal analyses presented in Table 3 from samples of the Placetas Batholith are considered representative of all the hornblende tonalites of the map area. It must be emphasized, however, that very few outcrops are available for sampling of unweathered quartz diorite, and should weathering characteristics be a function of composition, the average composition given in Table 3 will be biased.

Sample No.	Pc	Qtz	Hb	Op	Chl	Epi	Kf	Non-op Acc	Bi	Pc Comp.
CP-99	40.2	21.8	32.3	1.2	3.8	0.4	0.1	0.2	---	An 45-35
CP-92	47.5	19.4	27.0	2.0	3.1	0.6	0.4	---	---	
CP-317	45.8	18.0	32.3	2.3	1.1	0.5	---	---	---	An 32-37
CP-318	49.4	20.8	23.5	1.6	4.3	0.1	0.1	0.2	---	
CP-281	47.8	20.8	27.4	1.6	0.4	0.7	0.1	0.1	1.1	An 37-31
CP-367	49.9	25.9	18.1	2.3	1.8	1.8	---	0.1	---	
CP-430	48.6	18.1	28.1	0.4	4.6	0.1	---	0.1	---	
CP-432	37.9	21.9	35.9	0.9	2.9	0.2	0.2	0.1	---	An 35
CP-692	51.5	18.2	24.9	1.1	3.2	1.1	---	---	---	An 35
CP-695	42.1	15.3	37.3	2.0	1.7	1.6	---	---	---	An 42-44
CP-704	50.8	18.3	27.5	1.3	1.0	1.1	---	---	---	An 45-39
CP-738	50.3	23.6	16.5	2.0	2.4	---	5.1	0.1	---	
CP-822	45.3	21.9	24.6	1.9	5.2	0.5	0.4	0.2	---	
CP-902	46.1	19.9	22.3	1.6	6.0	3.7	0.2	0.2	---	
CP-906	35.8	9.2	52.5	2.3	---	---	---	---	0.2	An 48
Mean	45.9	19.5	28.7	1.6	2.9	0.8	0.4			

Table 3. Modal analyses of Placetas hornblende-quartz-diorite Batholith samples (values are in volume percent).

Hornblende tonalites are medium-to-coarse-grained with hypautomorphic texture. No protoclastic textures have been found in these rocks.

Plagioclase occurs as equant-to-twice-elongated, euhedral-to-anhedral grains. Maximum intercept diameters are 5 mm with most crystals being between 1 and 3 mm long. They are invariably twinned and in some rocks are progressively zoned. Most are quite fresh, but in some slides they are moderately to intensely sericitized. The plagioclase is of andesine composition in most of these rocks. Two samples from the pluton at Diferencia are oligoclases.

Hornblende is present in euhedral-to-anhedral crystals Individual crystals rarely exceed 5 mm in length, but in some hand specimens they appear larger due to aggregation of several crystals. Some poikilitically enclose euhedral plagioclase, oxides and quartz. The most common pleochroism is Z=medium green, Y=olive green, X=pale greenish-yellow. Absorption is Z>Y>X or Z=Y>X. Very rarely does Z=bluish-green. A few of these green hornblendes have cores of much paler amphibole, probably after original clinopyroxene.

The bulk of the quartz is anhedral against other principal minerals. A small amount of quartz enclosed in hornblende does show well developed hexagonal outlines in basal sections. It is not granulated, but much of the interstitial quartz shows moderate-to-strong undulatory extinction.

Potash feldspar, where present, is anhedral, interstitial to plagioclase and hornblende, untwinned and non-perthitic. Some is associated with chlorite, which suggests that a portion of the potash feldspar is the product of the biotite-chlorite transformation.

Biotite, an uncommon mineral in these rocks, is pleochroic from yellow or yellow-brown to deep brown. Some booklets are interlayered with chlorite. Most chlorite and epidote are associated with the hornblende and probably represent deuteric or hydrothermal alteration.

Opaque minerals are dominantly magnetite and ilmenite. Small amounts of chalcopyrite were observed in some of the polished sections. The principal non-opaque accessory is apatite; sphene is present in a few specimens.

Sericite is present in some rocks as an alteration product of plagioclase. All sericite was counted as original plagioclase in the modal analyses. Minor amounts of muscovite have been seen in some badly weathered outcrops. Prehnite veinlets are present in one of the thin sections examined.

In contrast to the leucotonalites, marginal foliation is not a characteristic feature of these plutons. In the western part of the map area, mixed rocks produced by injection of quartz diorite between schistosity planes of Duarte Formation schists are common. In the central and eastern portions of the map area contacts between country rock and plutons are sharp, but the tonalite itself shows no effects of chilling. These contrasting types of contact phenomena may be indicative of a deeper level of erosion as the result of greater uplift in the western part of the map area. Pegmatites have not been found, but aplite dikes have been seen in several of the intrusions.

Depth of Emplacement and Age of the Tonalites

Internal foliation, concordance of plutons with country rock, and regional greenschist facies metamorphism of the country rock, together with a superimposed contact aureole in the lower part of the amphibolite facies, are criteria diagnostic of plutons emplaced in the mesozone, as defined by Buddington (1959). These features are characteristic of the leucotonalites of the map area.

Hornblende tonalites have features more consistent with epizonal emplacement. Although the evidence is not conclusive, it suggests that hornblende tonalite plutons of the western part of the area were emplaced at greater depth than those cropping out to the east. None are believed to have been emplaced under the depth-intensity conditions which the writer assigns to the leucotonalites.

Because leucotonalites are found only in greenschist facies of the Duarte Formation, it would appear probable that they are older than the hornblende tonalites, which intrude several regionally unmetamorphosed formations in addition to the Duarte Formation. One of these is the Tireo Formation, which contains fossils of probable Cenomanian and Middle Campanian-to-Early Maestrichtion ages. Boulders of hornblende tonalite are found throughout the Magua Formation, which ranges in age from Late Maestrichtian (?) to Middle Eocene. If the assumption is made that all hornblende tonalites are of the same age, the time of emplacement is therefore post-Campanian, pre(?)-Late Maestrichtian or post-Campanian, pre-Middle Eocene.

Hornblendite

Two occurrences of hornblendite have been mapped. These bodies occur as marginal facies of the Los Cabirmas-Jumunuco hornblende tonalite in an area of slumped float and abundant vegetation. Tonalite at both of these localities is mesocratic, and thus, there appears to be a compositional gradation between mafic tonalite and hornblendite. Intrusive relationships into fine-grained Duarte country rock were observed, and from the distribution of float on the ridge crests, there appears to be an intimate intermixing of country rock and hornblendite.

Hornblendite typically exhibits two contrasting textures. One is porphyritic, in which euhedral hornblende crystals over 2 cm maximum diameter and forming more than 50% of the rock are set in a medium-grained groundmass of hornblende, quartz, epidote, and plagioclase. The second type has a coarse-grained seriate texture. In this type hornblende constitutes over 85% of the rock.

Known outcrops of hornblendite in the map area are marginal to plutons of hornblende tonalite. Two of the three hornblendite bodies mapped by Bowin (1966), including one northeast of Jarabacoa (Plate 1), occur within and close to the margins of foliated tonalites. The remaining hornblendite locale reported by Bowin (1966) refers to several lenticular pods within amphibolite rocks of the Duarte Formation. Amphibolitic rocks of the Duarte Formation are produced by contact metamorphism of the tonalites. It is inferred that tonalite underlies these hornblendite pods at very shallow depth and that all the hornblendites are genetically related to the quartz diorites of either the leucotonalite or hornblende tonalite type.

STRUCTURE

Metamorphic Rocks

The oldest rocks in the area, with possible exception of the serpentinized peridotites which may represent hydrated mantle, are metamorphic rocks of the Duarte and Amina Formations. Whereas those of the Duarte Formation are massive over large areas, Amina Formation rocks possess a well defined foliation everywhere. In both formations the average trend of foliation is N70°W. Within the Duarte Formation dips range from north, through vertical, to south, and deflections in the strike direction are pronounced in the proximity of batholiths. Within the Amina Formation, however, there is a greater constancy in the strike of foliation and virtually all dips are to the south. Moreover, dips of foliation tend to become more shallow northward, especially in the Rio Amina, where maximum breadth of the Amina Formation is exposed. A similar structural picture is seen in the central Dominican Republic, where the probable correlative of the Amina Formation, the Maimon Formation, shows a progressive shallowing of dip of foliation as the trace of the Hatillo Thrust is approached (Bowin, 1966, pp. 71-72). If the foliation flattening is causally related to thrusting, as seems likely, it would appear probable that the Hatillo Thrust continues westward into the present area but is buried beneath the cover of Miocene sedimentary rocks which overlie the northernmost exposures of the Amina Formation.

Scale of folding in the metamorphic formations has not been determined. Although foliation in the Amina Formation is parallel to compositional layering, which is believed to represent original sedimentary bedding, no marker units or top-bottom indicators have been found, and therefore, it is impossible to state whether the foliation reflects a continuous monoclinal section or whether the section is isoclinally folded. Similarly, the rare bedded cherts provide the only evidence of bedding within the Duarte Formation, and pillow structures, which are normally top-bottom indicators in greenstone formations, have not been observed.

Major Faults

The Bonao Fault

In the southeast corner of the map area greenschist facies rocks of the Duarte Formation are in fault contact with unmetamorphosed volcanic rocks of the Tireo Formation. This fault is the continuation of the Bonao Fault of Bowin (1966, p. 72). Because the greenschist facies rocks of the Duarte Formation are in contact with unmetamorphosed rocks of the Tireo Formation, the Tireo Formation is believed to be on the downthrown side. Topographic expression of the fault is a fault-line scarp with harder rocks of the Tireo Formation forming high mountainous country south of the fault. Trace of the Bonao Fault parallels the regional strike; when followed east into the area mapped by Bowin, the fault trace curves sharply to the south, as does the structure of the metamorphic rocks.

The Inoa Fault

The trace of the Inoa Fault from Las Mesetas to Las Brujas is marked by Magua Formation limestone. In the western extremity of the map area the most intense limestone deformation is evident. In this area the Amina Formation is brought into closest position with Duarte Formation rocks. Limestones of the Magua Formation from the northern limit of exposure to the Rodeo Basalt Member of the Magua Formation consist of an alternation of sheared and crumpled segments and apparently undeformed portions. Shear planes are essentially vertical. Limestone in the vicinity of Las Brujas is well exposed in two small arroyos, where it is also seen to be intensely sheared with a multitude of vertical shear planes. Cobbles and boulders of the Inoa Conglomerate in contact with the Placetas Batholith are stretched in the direction of the surface trace of the fault. No deep vertical exposures were seen, however, and it is not known if the greatest elongation of the clasts is in the horizontal or dip direction of the fault. Tonalite along the trace of the fault is mildly bleached and strongly altered with epidote. The fault trace east of the Placetas Batholith is marked by isolated slices of Magua limestone. Fault contact with the Duarte Formation appears to continue to Pedregal. In the Rio Janico contact between the Inoa Conglomerate and the Duarte Formation is not exposed.

North of Los Caguelles, exposures of basal conglomerate and fossiliferous (orbitoidal) limestone of the Velazquitos Formation occur and continue at the base throughout the mapped area. In the Rios Guanajuma and Yaque basal conglomerate is clearly seen to rest unconformably on Duarte Formation rocks. In the section of this report concerning origin of the Tabera Group, it was suggested that the entire southern contact of the Inoa Conglomerate and Velazquitos Formation was originally the surface trace of a major fault, the eastern portion of which is not yet exposed by erosion. There would be no valid reason for suggesting this if the basal units of the Velazquitos Formation were succeeded by shallow-water marine sediments, for in a shallow-water marine transgression the surface of transgression would be beveled to a planar surface. If, however, the sediments immediately above the basal unit of a formation indicate a deep-water depositional environment, considerable relief could still be maintained along the surface of the unconformity. Such is believed to be the case with regard to the Velazquitos Formation.

The Amina Fault

The plane of the Amina Fault is not exposed. The steep dip of the Inoa Conglomerate, within 15 m of the Amina Formation as seen in the Rios Amina and Inoa, suggests that the fault dips steeply. Only in the Rio Amina is there any pronounced stretching of the clasts of the Inoa Conglomerate (Fig. 6).

The Tavera Fault

The plane of the Tavera Fault is well exposed in the Rio Guanajuma, where it is seen essentially to have a vertical dip. Unpublished results of test drilling at the dam site at Ranchos de Tavera indicate that at this locality the fault plane dips at 78°S.

From stratigraphic interpretation, the writer considers that the south side is down relative to the north. Steepening of dips in the Represa Conglomerate north of the fault may be interpreted as drag, indicating the opposite sense of movement. Objections to this are both structural and stratigraphic:

(1) the distance over which steep dips north of the Tavera Fault are found is improbably large to be attributed to drag, when it is taken into consideration that the competent Represa Conglomerate is in fault contact with incompetent mudstones of the Velazquitos Formation;

(2) a relative movement of south side down is in the same sense as is required for the Amina Fault. It is possible that the Amina and Tavera Faults are essentially the same;

(3) the opposite sense of movement would imply that the Represa Conglomerate was stratigraphically above the mudstones and sandstones of the Velazquitos Formation. The limestone at the top of the Represa Conglomerate, however, is lithologically similar and bears the same species of foraminifera as does the limestone above the basal conglomerate of the Velazquitos Formation. The writer interprets that these limestones are correlatives.

GEOLOGIC HISTORY

The oldest supracrustal rocks in the area are the schists of the Amina Formation and metabasalts of the Duarte Formation. Mineralogy and compositional layering of the Amina schists suggest that the original rocks were tuffs or tuffaceous sediments of intermediate-to-acid composition. Metaquartz keratophyres are a major component of its correlative, the Maimon Formation, in the central Dominican Republic (Bowin, 1966, p. 25). Minor limestone lenses in both Amina and Maimon Formations indicate that they were deposited under marine conditions. Minor bedded cherts within the Duarte Formation indicate that the lavas were deposited under marine conditions. Furthermore, the sodium-to-potassium ratios of the metabasalts indicate their affinities with the types of tholeiites found in deep ocean basins. Inasmuch as the two formations are separated by serpentinized peridotite, or by a graben of Oligocene sedimentary rocks, and fossils have not been found in either of the formations, their stratigraphic relationships are unknown.

From the distribution of isograds within the Duarte Formation and the fact that the Amina Formation is entirely within the greenschist facies, it may be suggested that the Amina Formation is stratigraphically below the Duarte Formation. This model assumes that the movement on the Amina Fault is primarily dip-slip. This stratigraphic relationship would be the inverse of the commonly accepted picture of oceanic crust, where basalt immediately overlies the mantle or its hydrated equivalent, serpentinized peridotite. Seismic refraction studies in deeper parts of the Caribbean Sea (Officer *et al.*, 1959; Ewing *et al.*, 1960), however, indicate that in the Yucatan and Venezuelan Basins, crustal sections are slightly thicker than in typical oceanic crust. Donnelly (1964) has suggested that these crustal differences are fundamental and the boundaries between plates of contrasting crustal thickness determine the position of island arc formation. Thus, if the Caribbean crust is thicker than typical oceanic crust, it may also be compositionally different, and the stratigraphic relationship suggested above may not be as anomalous as it first appears.

However, the fact that the Duarte Formation and other formations south of it are abundantly intruded by plutons of various types, whereas the Amina and Maimon Formations are not, may suggest that the thermal histories of these two terrains were so different that they may have been brought together by large lateral translations. Seismicity indicates that the Greater Antillean region is a zone of transcurrent displacement (Molnar and Sykes, 1969). The possibility exists, therefore, that the Amina, Inoa and Loma Caribe Faults are part of this major left-lateral transcurrent shear system. The large change in trend of the Loma Caribe Fault and in the grain of the metamorphic rocks near the town of La Vega (Bowin, 1966, Plate 1, and Plate 1 of this report) is a large change in direction for a major shear system. This bend, which is on the projection of the Beata Ridge, however, may be a relatively late impressed strain associated with downthrusting of the Americas plate with respect to the Caribbean plate (Bracey and Vogt, 1970). Paleomagnetic studies on rock units in the map area and in the central Dominican Republic may give evidence for or against the oroclinal nature of this bend. Should the orocline be demonstrated, transcurrent faulting of major proportions would still not be demonstrated; there is, as yet, no direct geological evidence for anything other than dip-slip movement on the Amina, Inoa and Loma Caribe Faults.

In summary, early geological history of the map area and of the Dominican Republic in general, is obscure. Two models have been put forward and several more could be added, but available factual information does not allow one to make a choice from among them. More detailed field mapping, together with radiometric dating studies, may help to reduce the number of unknowns and, thus, lead to a single most probable historical model.

Following metamorphism of the Duarte Formation, with concomitant intrusion of the leucotonalites, a period of uplift and erosion took place. Tireo volcanism took place during most of Late Cretaceous time and resulted in deposition of several kinds of volcanic rocks, including andesitic lava and tuff, and quartz keratophyre. The last stages of Tireo volcanism were probably associated with generation of great volumes of quartz diorite magma, which are represented by dominantly discordant plutons of hornblende tonalite. These masses intrude the Duarte Formation, the Tireo Formation, the Los Ranchos Formation (Bowin, 1966, Plate 1) and rocks on the south flank of the Cordillera Central (Weyl, 1941, Karte 11).

Evidence for deformation involving folding in the latest Cretaceous (probably Early Maestrichtian) has been presented by Bowin (1966, p. 81). This period of folding may be related to the time of intrusion of the hornblende tonalites. Latest Maestrichtian(?)-to-Middle Eocene time was represented by basaltic volcanism and deposition of boulder conglomerates, conglomeratic volcanic breccias, and minor limestones and sandstones. The coarser detritus and lenses of bioclastic limestone of this, the Magua Formation, probably accumulated in deep water as a consequence of submarine landslips related to faulting. Conglomerates of the Magua Formation contain boulders of hornblende tonalite, which indicates that by Middle Eocene time or possibly as early as latest Maestrichtian time, some, at least, of the hornblende tonalites were exposed to erosion. The present site of the Cordillera Central was established as a more or less permanent topographic high for the remainder of geologic time.

Rocks of the Magua Formation were folded parallel to earlier structures formed during regional metamorphism. The folding took place in Middle-to-Late Eocene time. Major deformation is also recorded in the central Dominican Republic at this time; the Maimon Formation was thrust upward and over Cretaceous and Early Tertiary rocks to the northeast (Bowin, 1966,

p. 82). The northward shallowing of dips of foliation in the Amina Formation suggests that it also was faulted upward and northward at this time. Faulting possibly related to this Late Eocene period of deformation may have controlled the site of deposition of the Los Caguelles Limestone Breccia.

Movement on the Inoa Fault in Early Oligocene time probably controlled the formation of a sedimentary depositional basin on the fault's north side. In the eastern portion of this basin marine conglomeratic sandstones were deposited, whereas farther to the west red conglomerates accumulated subaerially. Areas of subaerial deposition underwent minor marine transgressions from time to time with resultant deposition of better-sorted gray conglomerates and sandstones.

A limestone unit at the top of the Represa Conglomerate has been correlated with that at the base of the Velazquitos Formation. Apparently, tectonism ceased and the limestone was deposited in shallow-water marine conditions transgressing across the Inoa Fault and over part of the former source area. Although somewhat subdued and of small areal extent, the source area to the south continued to supply an abundance of immature sand and mud, which accumulated below wave base forming the sandstones and mudstones of the Velazquitos Formation. Folding and faulting accompanied by tectonic movements of the serpentinites took place between Early and Middle Oligocene time. Following a period of erosion, marine seas again advanced over the area. One of the margins of this basin is near the town of Moncion, where shallow-water marine Moncion Limestone is exposed. Sands, mineralogically more mature than those of the earlier Velazquitos Formation, together with lime mud and sand, accumulated along the basinal margins. Periodically, these sands, and infrequently, gravels were swept off this shelf and carried downslope by turbidity currents into the deeper part of the basin, where deep-water clays were accumulating to form the Janico Formation. Thus, both during Early and Middle-to-Late Oligocene time, the deeper part of the sedimentary basin was located in the eastern part of the area. An episode of mild folding and erosion brought the Oligocene epoch to a close.

Boulder conglomerates, which were deposited along a marine shoreline, are the first Miocene deposits of the Cibao Basin. Deposition of these was followed by the shallow-water marine accumulation of sands of the Cercado Formation. Middle and Late Miocene claystones, marls, and sandstones of the Gurabo and Mao Formations, exposed north of the map area, are the last thick accumulation of sediments of the Cibao Basin. No important post-Miocene folding took place in the area. Small-scale faulting took place within the graben occupied by the Inoa Conglomerate.

REFERENCES

Bailey, E.H. and R.E. Stevens, 1960, Selective staining of K-feldspar and plagioclase on rock slabs and thin section: Am. Min., vol. 45, p. 1020-1025.

Bermudez, P.J., 1949, Tertiary smaller foraminifera of the Dominican Republic: Cushman Lab. Foram. Research Spec. Publ. 25, p. 1-322.

Bolli, H.M., 1957, Planktonic foraminifera from the Oligocene-Miocene Cipero and Lengua Formations of Trinidad, B.W.I.: *in* Studies in Foraminifera, A.R. Loeblich, Jr., ed., U.S. Nat. Mus. Bull 215, p. 97-123.

Bowin, Carl, 1960, Geology of central Dominican Republic: Unpublished Ph.D. Thesis, Princeton University. 211 p.

________, 1966, Geology of the central Dominican Republic: a case history of part of an island arc): Geol. Soc. Amer. Memoir 98, p. 11-84.

Bracey, D.R. and P.R. Vogt, 1970, Plate tectonics in the Hispaniola area: Geol. Soc. Amer., Bull. 81, p. 2855-2860.

Brannock, W.W. and S.M. Berthold, 1953, The determination of sodium and potassium in silicate rocks by flame photometer: U.S.G.S. Bull. 992, pt. 1, p. 1-14.

Buddington, A.F., 1959, Granite emplacement with special reference to North America: Geol. Soc. Amer., Bull. 70, p. 671-747.

Coombs, D.S., 1961, Some recent work on the lower grades of metamorphism: Australian Jour. of Sci., vol. 24, p. 203-215.

Cucurullo, O., 1961, Un Capitulo sobre la Geografia de Santo Domingo, Primera Parte Introduction e Divisiones Fisiograficas: Panta Rhei, Santo Domingo, vol. 1, no. 1, p. 3-10.

Donnelly, T.W., 1959, Geology of St. Thomas and St. John, Virgin Islands: Unpublished Ph.D. Thesis, Princeton University.

________, 1964, Evolution of the eastern Greater Antillean island arc: Amer. Assoc. Petrol. Geol., Bull. 48, p. 680-696.

Dunbar, C.O. and J. Rodgers, 1957, Principles of Stratigraphy, John Wiley and Sons, Inc., New York. 356 p.

Engel, A.E.J., C.G. Engel, and R.G. Havens, 1965, Chemical characteristics of oceanic basalts and the upper mantle: Geol. Soc. Amer., Bull. 76, p. 719-734.

Eskola, P., 1939, Die metamorphen gesteine: *in* Die Entstehung der Gesteine, T.F.W. Barth, C.W. Correns, P. Eskola, eds., Springer, Berlin, p. 263-407.

Ewing, J., J. Antoine, and M. Ewing, 1960, Geophysical measurements in the western Caribbean Sea and in the Gulf of Mexico: Jour. Geophys. Research, vol. 65, p. 4087-4126.

Green, J. and A. Poldervaart, 1955, Some basaltic provinces: Geochimica et Cosmochimica, Acta 7, p. 177-188.

Heneken, T.S., 1853, On some Tertiary deposits in Santo Domingo, with notes on the fossil shells by J.C. Moore, and on the fossil corals by W. Lonsdale: Quart. Jour. Geol. Soc. London, vol. 9, p. 115-134.

Hess, H.H., 1966, Caribbean research project, 1965, and bathymetric chart: *in* Caribbean Geological Investigations, H.H. Hess, ed.: Geol. Soc. Amer. Memoir 98, p. 1-10.

Hutton, C.O., 1940, Metamorphism in the Lake Wakatipu region, western Otago, New Zealand: New Zealand Dept. Sci. Ind. Research Geol. Memoir 5, p. 1-84.

Maury, C.J., 1917, Santo Domingo type section and fossils: Bull. Amer. Paleontology, vol. 5, no. 29, p. 1-251.

Melson, W.G. and T.H. Van Andel, 1966, Metamorphism in the Mid-Atlantic Ridge, 22°N latitude: Mar. Geol., vol. 4, p. 165-186.

Miyashiro, A., 1961, Evolution of metamorphic belts: Jour. of Petrology, vol. 2, p. 277-311.

________, 1968, Metamorphism of mafic rocks: *in* Basalts (the Poldervaart treatise on rocks of basaltic composition), H.H. Hess and A. Poldervaart, eds., Interscience Publishers, p. 799-834.

Molnar, P. and L.R. Sykes, 1969, Tectonics of the Caribbean and Middle America regions from focal mechanisms and seismicity: Geol. Soc. Amer., Bull. 80, p. 1639-1684.

Moore, J.C., 1849, On some Tertiary beds in the island of Santo Domingo, from notes by J.S. Heniker (sic), with remarks on the fossils: Quart. Jour. Geol. Soc. London, vol. 6, p. 39-53.

Moore, J.G., A. Grantz, and M.C. Blake, 1961, The quartz diorite line in northwestern North America: U.S.G.S. Prof. Paper 424C, p. 87-90.

Officer, C.B., J.I. Ewing, J.F. Hennion, D.G. Harkrider, and D.E. Miller, 1959, Geophysical investigations in the eastern Caribbean: summary of the 1955 and 1956 cruises: Physics and Chemistry of the Earth, vol. 3, p. 17-109.

Peterson, D.W., 1961, Descriptive modal classification of igneous rocks, AGI Data Sheet 23: Geotimes, vol. 5, no. 6, p. 30-36.

Seki, Y., 1961, Pumpellyite in low-grade metamorphism: Jour. of Petrology, vol. 2, p. 407-423.

Shido, F., 1958, Plutonic and metamorphic rocks of the Nakoso and Iritono districts in the central Abukuma Plateau: Jour. Fac. Sci., Univ. of Tokyo, Sec. 11, vol. XI, pt. 2, p. 131-217.

Stevens, R.E. and W.W. Niles, 1960, Chemical analyses of the granite and the diabase: *in* Second Report on a Cooperative Investigation of the Composition of Two Silicate Rocks, U.S. Geol. Survey Bulletin 1113, p. 3-43.

Turner, F.J., 1968, Metamorphic Petrology, McGraw-Hill Book Co., 403 p.

Vaughan, T.W., 1933, The biogeographic relations of the orbitoid foraminifera: Proc., Nat. Acad. of Sci., vol. 19, p. 922-938.

________, W. Cooke, D.D. Condit, C.P. Ross, W.P. Woodring, and F.C. Calkins, 1922, Un Reconocimiento Geologico de La Republica Dominicana: Servicio Geologico de La Republica Dominicana, Memoir 1, 268 p.

Weyl, Richard, 1941, Bau und Geschite der Cordillera Central von Santo Domingo: Deutsch-Dominikanisches Tropenforschungsinstitut, Veroffentlichungen 11, 60 p.

PHYSICAL GEOGRAPHY OF NORTHWEST DOMINICAN REPUBLIC

Gustavo A. Antonini
Geography and Latin American Studies
University of Florida
Gainesville, Florida

CONTENTS

LIST OF ILLUSTRATIONS

Figure

Plate

INTRODUCTION

General Statement

This paper presents an analytical description of the salient landform features and associative surficial lithologies of the Linea Noroeste (Northwest), Dominican Republic. Regional variability of climate, topography, geology, and vegetation all combine to make the study area a suitable laboratory to examine a wide array of subhumid and arid subtropical landforms.

The aims of this study are to examine the landscape-forming processes that have transformed geologic structure into distinct landform units, to show the relationship between broad patterns of physical features and geologic structure, and to characterize each landform's set of lithologic, soils, slope and drainage features. The paper is intended to be a regional geomorphology of northwestern Dominican Republic and includes a descriptive examination of the complex physical patterns that constitute this broad geographical region.

Field and Laboratory Methods

During the course of a 27-month stay in the Dominican Republic, ample opportunity was found to study the geomorphology and map the surficial deposits of the Linea Noroeste region. About five months between July 1965 and September 1967 were devoted to collecting all basic information on geology and surface morphology using field traverse mapping techniques. One month in the spring of 1966 was spent obtaining soil profile data from 50 pit excavations. Additional generalized soils data were collected while performing a separate study, which evaluated natural environmental factors that determine potential agricultural productivity for selected zones within the study region (Antonini *et al.*, 1967). A map showing the distribution of the writer's traverses is found in Figure 1.

Prior to going to the Dominican Republic, a period of six months was spent in obtaining aerial photographic and map coverage, annotating the photographs, and reviewing existing literature. Most geologic and morphologic mapping for this study was done on aerial photographs taken by the U.S. Army Air Force in 1948 (scale approximately 1:40,000). Transfer and scale reduction of geologic features from the aerial photographs to the respective U.S. Army Map Service Series E733 and E0734, 1:50,000-scale topographic and photo maps was accomplished by radial line compilation and use of both a Saltzman P-1414A vertical reflecting projector with restitutional easel and a Keuffel and Esser model adjustable vertical sketchmaster. The base map was then reduced to a 1:100,000 scale using an A. Ott precision pantograph, and all lithologic boundaries were plotted on dimensionally stable mylar.

A total of 557 rock samples were collected in the field during the periods July 1965-March 1967 and June 1-10, 1969. All coarse-, medium- and fine-grained fragmental sediments and rocks were classified by the writer according to Dunbar and Rodgers (1957). Unconsolidated surficial materials and soils were grouped according to the system outlined in the U.S. Department of Agriculture Soil Survey Manual (1951). Visual, microscopic and x-ray analyses carried out by Mrs. Ina B. Alterman at the Department of Geology, Columbia University, on 146 samples were used in compiling the surficial geologic maps presented herein. In addition, samples of metamorphic rocks found along the southern flank of the study region were studied in thin section by H.C. Palmer, Department of Geophysics, University of Western Ontario, Canada.

Acknowledgments

It is a pleasure to acknowledge the counsel and encouragement given by Dr. Leonard Zobler, Department of Geology and Geography, Barnard College, Columbia University. Dr. Zobler visited the writer in the field during August and September of 1966 and was a stimulating discussant and acute observer who helped mold the initial geomorphological classification. I also wish to acknowledge greatfully the valuable assistance of Drs. H.C. Palmer, Department of Geophysics, University of Western Ontario, Canada, and Frederick Nagle, Department of Geology, University of Miami, Florida. Dr. Palmer accompanied the writer in the field during June 1969 and performed the thin section laboratory study of the metamorphic

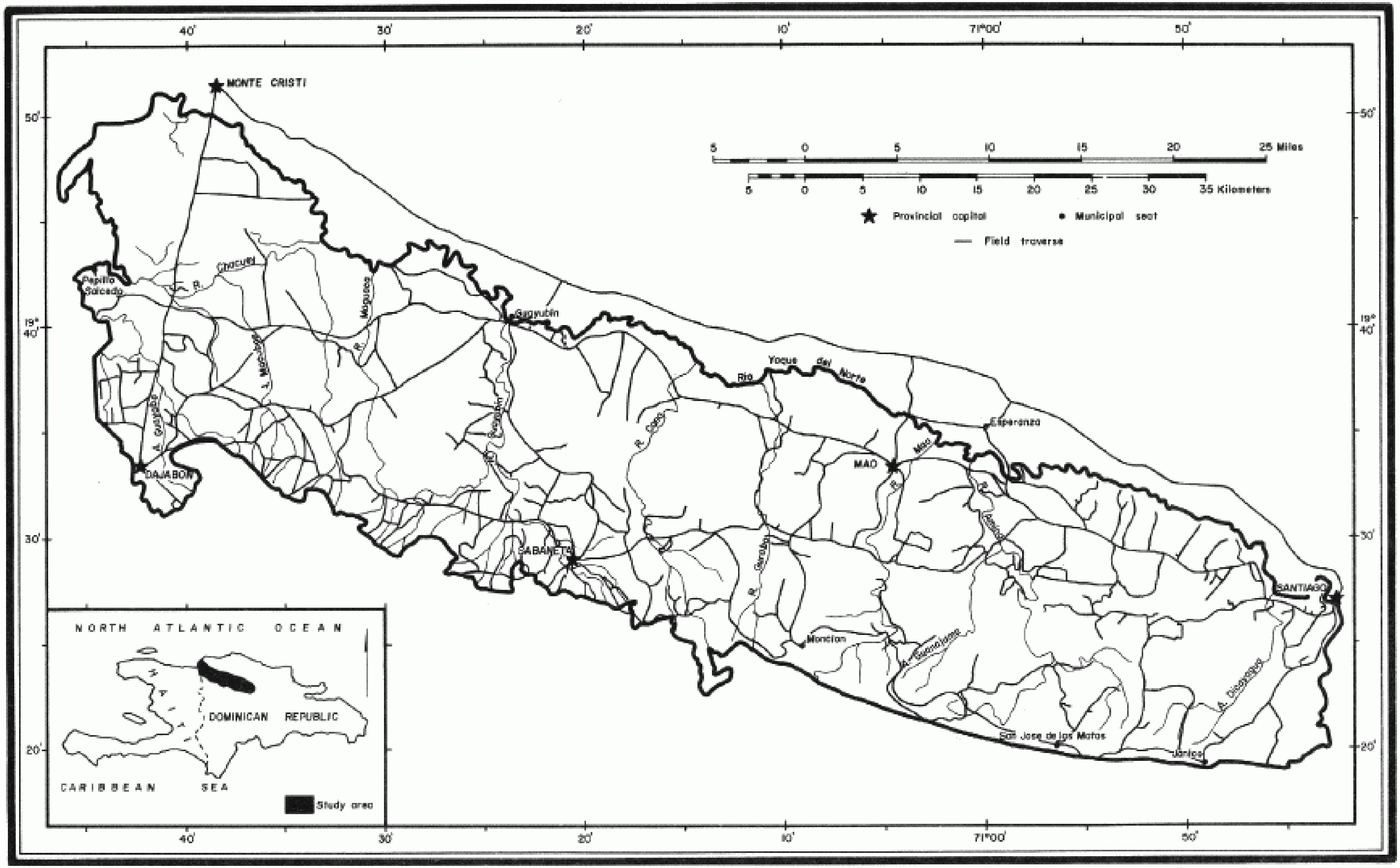


Figure I. Map showing field traverses made by G. A. Antonini in northwestern Dominican Republic, 1965–67.

rock samples. All colleagues read the manuscript, and their comments, criticisms and suggestions have been most helpful in preparation of this study.

As a piece of field research undertaken in a developing country during a revolution, this study owes an incalculable debt to the friendship and generosity of the Dominican people who made it possible. In particular, Lic. Victor M. Espaillat M. obtained most financial and logistical support without which this study could not have been performed. The Universidad Católica Madre y Maestra provided housing facilities and funds to cover some field expenses, while the Asociación para el Desarrollo, Inc. offered a Land Rover with complete maintenance for the field season. An OAS (Pan American Union) travel and research fellowship partially supported field work, and the U.S. Agency for International Development provided a research grant to defray the cost of field equipment, aerial photographs and bibliographic photocopy expenses.

REGIONAL SETTING

Location

The study area is located in the Dominican Republic northwest of the city of Santiago de los Caballeros (see inset map in Plate 1). The eastern and northern limits coincide with the Yaque del Norte River with the southern perimeter being the physical boundary between the Cibao Valley and Cordillera Central geomorphic provinces (Vaughan *et al.*, 1921, p. 26). The Massacre River, which coincides with the international boundary between the Dominican Republic and Haiti, was selected as the western limit. The area thus outlined contains approximately 2660 square km (1663 square miles) or 5% of the Dominican Republic.

Climate

Climatic regimen of the northwest is controlled by: (1) changes in prevailing atmospheric pressure systems; and (2) topographic barriers and land surface complexities. Both controls act interdependently to produce significant regional climatic patterns which, in turn, affect the type and rate of weathering, mass wasting, and erosion found throughout the mapped area.

The dominant climatic control is the change in atmospheric circulation from high pressure during the winter season to low pressure during summer months. In the winter the northwest is dominated by the influence of the stable high pressure system over the North American continent. During this period, winds blow forcefully and steadily from the northeast. Weak winter cyclones occasionally push polar continental air out into the Atlantic sufficiently far to affect the northwest. According to Alpert (1939, pp. 18-24), these *nortes* produce prolonged light drizzle for several days throughout the winter months.

The equatorial low pressure system dominates the scene during summer months with winds from the southeast quadrant. This relatively unstable air mass is conducive to the formation of thunderstorms which occur quite frequently during this season. Summer-type atmospheric conditions also influence the development of the tropical hurricane which occasionally produces disasterous effects, mostly in the form of torrential rains.

The moisture-carrying capacity of air masses over the northwest is affected by topographic barriers. As winds come off the ocean and strike the north coast of the Dominican Republic, they encounter the Cordillera Septentrional. This northern coastal mountain range acts as the major fault barrier element to the trade winds. Moist air is cooled adiabatically and dry weather prevails. The map in Figure 2 illustrates the northwest's location with respect to the barrier mountain range. Note that the study area's northernmost strip is situated within the rain shadow of the east-west-trending Cordillera. Conversely, the southern fringe of the study region is located at a topographically higher elevation along the northern flank of the Cordillera Central. This southern zone thus receives considerably more rainfall due to orographic lifting.

Analysis of Dominican climatological data shows that precipitation varies greatly in the northwest from 507 mm at Villa Vasquez to 1250 mm at San Jose de las Matas. Annual

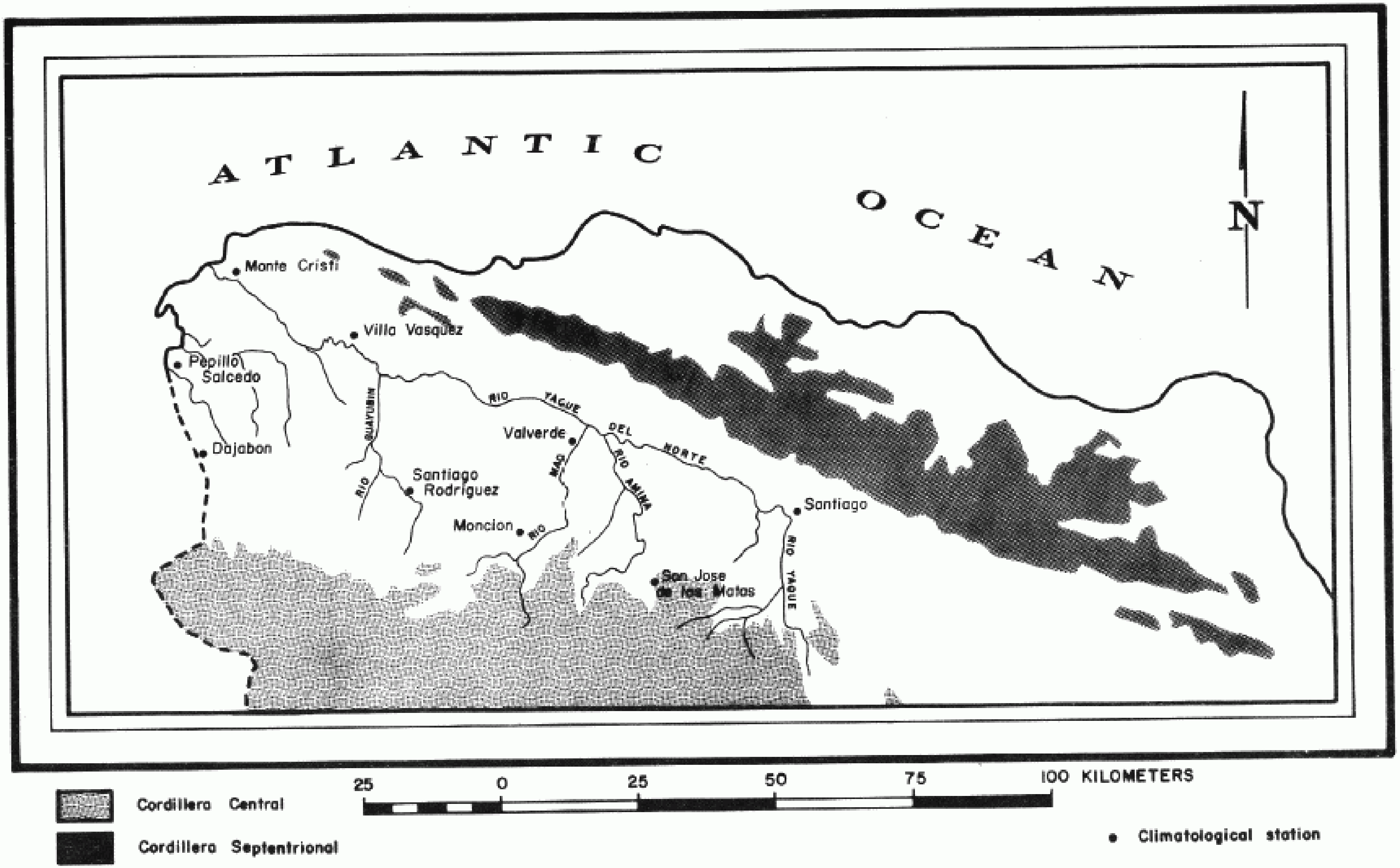


Figure 2. Map showing landforms that influence climate in northwestern Dominican Republic.

temperature range is small, however, from an average 27.5°C in July to 22.2°C in January. Of significance are high temperature values which directly influence moisture availability via water loss through evapotranspiration. Differences in precipitation at selected stations are presented as graphs in Figure 3[1] and illustrates a bi-modal precipitation regimen with the two wettest periods occurring between May-June and September-November. Variations do occur in notable fashion, however; generally, the northern portion of the study area is dry throughout most of the year. This extremely dry zone is concentrated between Mao (Valverde) and Villa Vasquez. Constantly high temperature there causes potential evapotranspiration to exceed precipitation during the entire year. In the northeast at Santiago, spring rains are of sufficient intensity to produce soil moisture recharge during April and May. The situation is reversed in the extreme northwest at Monte Cristi. Here, it is autumnal rains that evidence enough intensity to reverse water deficit and make a little water available for plant growth. Along the southern fringe of the study area, adiabatic cooling caused by higher elevation induces orographic precipitation and greater moisture availability. Examination of water balance graphs in the lower half-page of Figure 3 indicates that the southeastern area has the greatest water surplus. The trend is one of decreasing surplus westward to Dajabon.

Such examination of prevailing weather patterns points out variability of precipitation and deficiency of available soil moisture as the prime climatological characteristics of this subtropical environment. Climatic differences which significantly affect evolving geomorphological processes derive from the effectiveness and availability of soil moisture and are dependent upon annual and seasonal distribution of rainfall. In addition, precipitation is essential to disaggregation of consolidated material and to act as a transporting agent. Total rainfall and storm intensity are important climatic elements.

Variation in annual and seasonal precipitation would affect landforms of the study region even if they were perfectly flat and composed of a single, uniform surficial material. Because landforms are varied, several other moisture factors dependent, in part, upon surface lithology and morphology are superimposed on rainfall. These are the different infiltration rates, permeabilities, and moisture-holding capacities of the materials, and the water runoff received in depressions and lowlands from uplands. Both dependent moisture factors and prime regional climatological components are responsible for local surface and near-surface lithologic transformations.

Vegetation

Three basic vegetation zones which occur in the northwest are: (1) the *monte* or *monteria*, a subtropical forest zone; (2) *breña*, a thorn thicket and cactus cover; and (3) the *savana* or open grassland. Field study shows that transitional zones may occur between the major vegetation units. Physical interrelationships developed between vegetation, geology and surface morphology are shown in Figure 4.

The *monte* or forest zone is found capping shallow calcareous soils on the high and more remote cuestas along the Zamba Hills and metamorphic inliers to the south. Today, the forest zone contains few of the once numerous stands dominated by mahogany. A riverine forest-type is presently found on the Massacre River floodplain; frequent flooding by this perennial stream provides sufficient moisture to allow such luxuriant vegetative growth in this semiarid climatic zone.

Breña, or the thorn thicket and cactus zone, covers much of the present northwest region. Characteristically, thorn thicket invades a forested area after farmers abandon a worked-out field in the endless shifting from site to site. This ecological succession represents soil depletion, for the thorn thicket can never rejuvenate the eroded mantle completely.

The southwestern sector of the study region is a grassland or *savana* zone. Today, the ecological succession induced by man's agricultural activities is transforming this zone in the east into a closed *savana* or parkland. Within the past two decades there has been a large areal increase in the number of xerophytic shrubs. The western frontier area still retains the *savana limpia* or open grassland appearance which extends to the Haitian frontier.

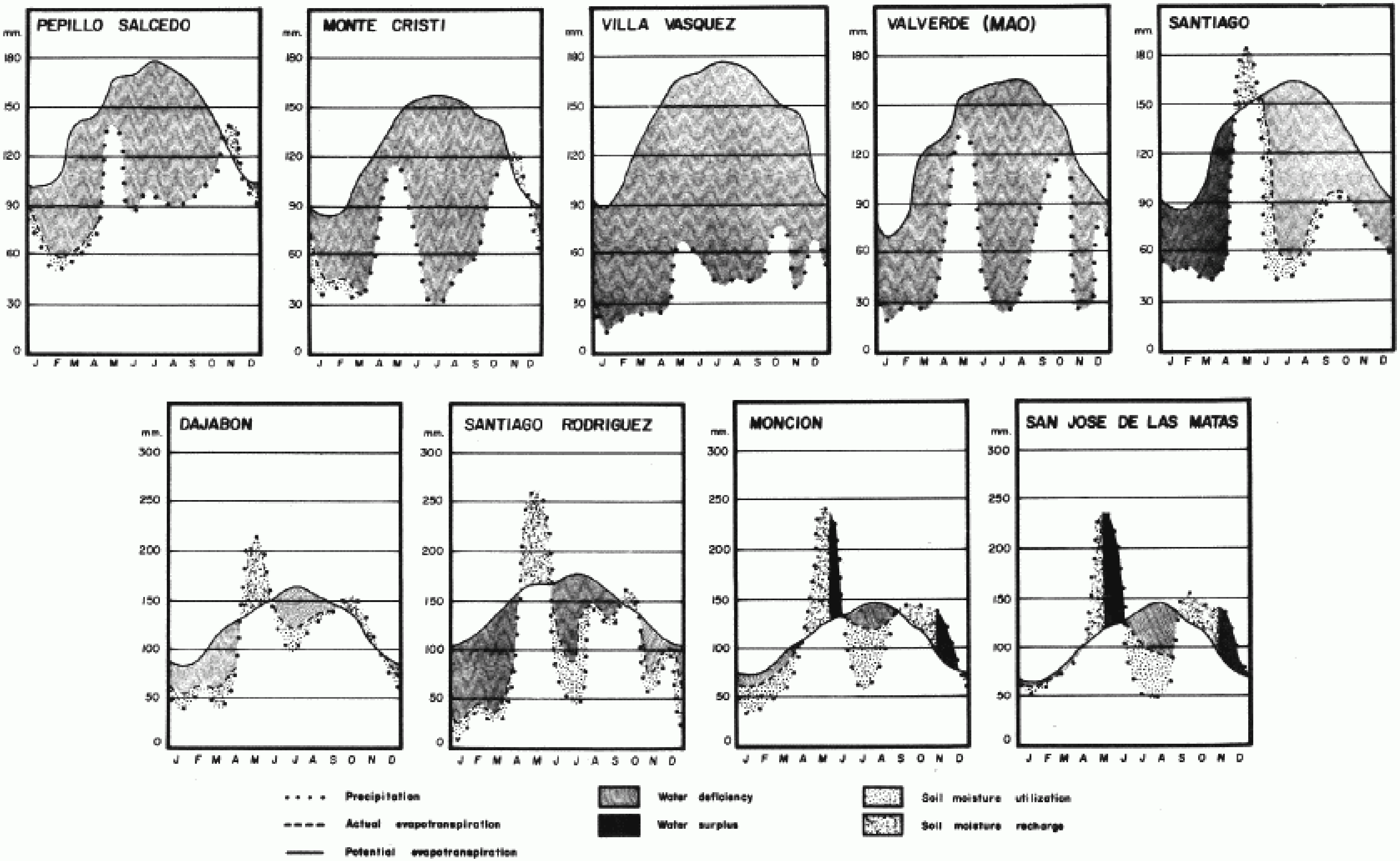


Figure 3. Water balance graphs of selected climatological stations in northwestern Dominican Republic. (Adopted from the study by Antonini, Zobler, and Timofeeff, loc. cit.)

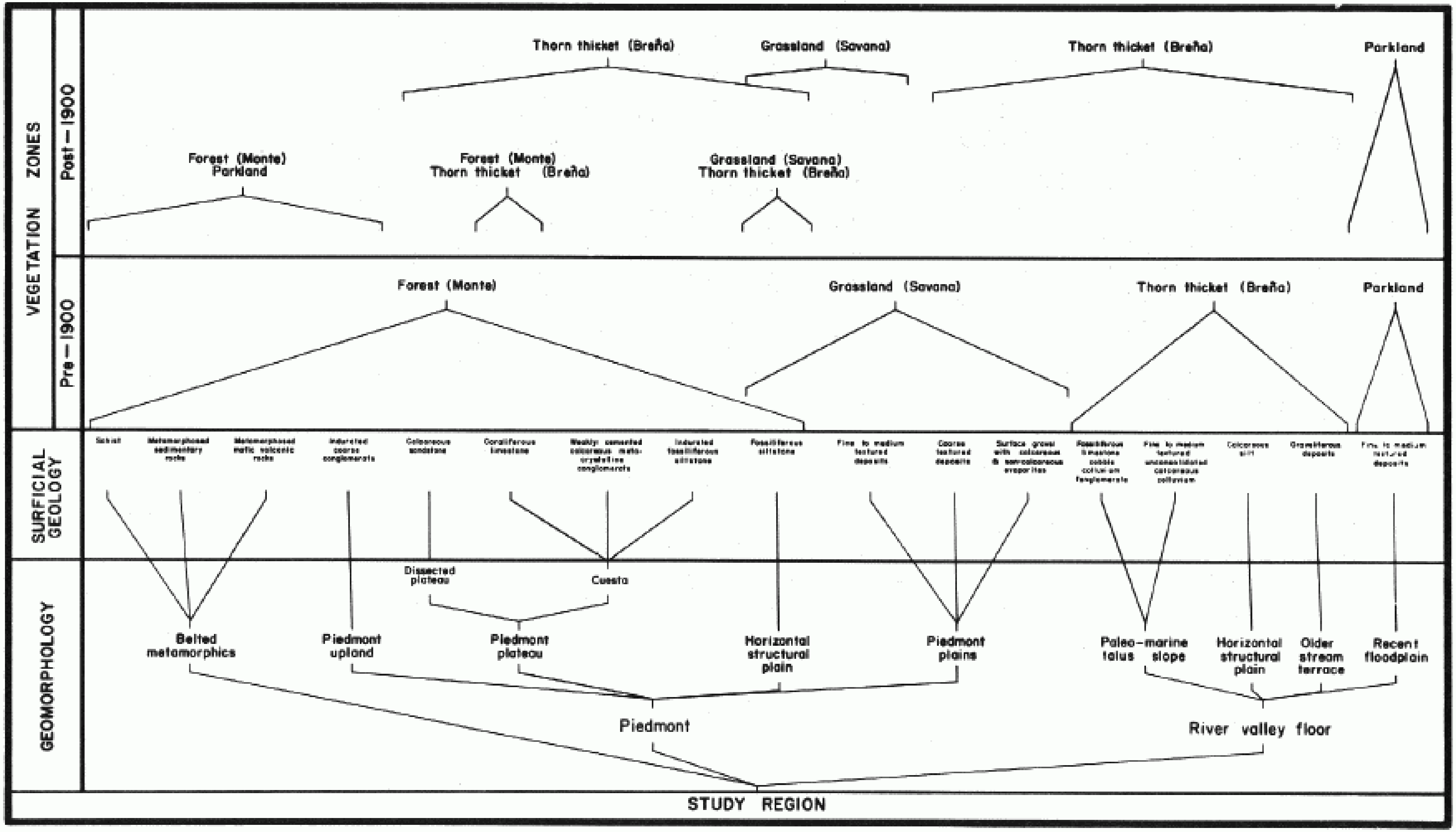


Figure 4. Diagram showing the interrelationship between geomorphology, surficial geology and vegetation zones. (Partially adapted from the study by Antonini, Zobler and Timofeeff, loc. cit.)

A small area of parkland vegetation is found east of the thorn thicket zone near Santiago; this is actually a transitional zone, where the open-foliated acacia trees, tall columnar cactus, mesophytic palms and mango are found side by side. Parkland vegetation is also found along alluvial floodplains and stream terraces of the Yaque River and its tributaries, and is seen as a transitional zone between the thorn thicket and forest from San Jose de las Matas to Moncion.

In a landscape occupied by man as long as the Linea Noroeste region with a system of slash-and-burn agriculture (*tumba*), it is likely that man-induced or accelerated erosion has had an important impact on surface morphology. In fact, sheetwash, gullying and soil erosion are common degradational processes found operative within the *breña* zone. Perusal of the tree diagram in Figure 4 indicates that this thorn thicket and cactus zone covers a far greater area today than during the pre-1900 period. Within the past century, extensions of subsistence farming into the *monte* zone stripped most of the forest cover from it. The *breña* quickly invaded this piedmont zone and to date maintains its primate role. Man-induced changes in vegetation have also affected surface features and lithologies within the study region. A geomorphic system initially in equilibrium among its elements of rocks, climate, and slopes has been seriously disturbed by removal of a protective natural vegetative cover by mechanical influences of farming. Net effect of these changes has been to shift equilibrium in the direction of greater erosion, which manifests itself in removal of topsoil, deep gullying, and increased flooding and deposition in the lowlands.

Surface Morphology

Broad patterns of physiographic features within the study region are due to geologic structures and related landforms.[2] The map in Figure 5 illustrates general distribution of major physiographic units.

Originally a seaway during the Miocene epoch, subsequent uplift and development of the Cordillera Septentrional to the north have transformed the study region into an interior plateau and plains landscape now remote from the sea. Geologic structure parallels the northwest-southeast orientation of the Cordillera Central's crystalline basement lying to the south. Major physiographic units and their subregions found within the study area are mapped in Figure 5. From south to north they are: (1) belted metamorphics; (2) the piedmont, consisting of an upland, plateau and plains surfaces; and (3) the river valley floor, comprising stream terraces, recent floodplain, and shoreline deposits.

The complex physiography of the northwest is an important factor that influences the macroclimatic regime and affects the type and rate of rock weathering; it is also an important soil-forming agent. Development of these diverse physiographic regions reflects the interaction of several geomorphic processes. Differences in elevation resulting from diastrophism permit gravity to move loose material downslope from one location to another. Elevation ranges from 558 m to sea level, giving high relative relief for the region and providing steep gradients for streams to acquire sufficient energy to carry weathered material in suspension and as traction load. The varying resistivity of surficial materials to weathering, mass wasting and erosion also affects landform development. It is clear from the stratigraphic sequence for the northwest in Plate II that a variety of materials at contrasting elevations exist in the Linea Noroeste. These materials range from complex metavolcanic and metasedimentary rocks to variously indurated limestones, siltstones, conglomerates, and unconsolidated alluvial sediments. Each weathers in a unique manner and is associated with a particular set of landform assemblages.

INTRODUCTION TO REGIONAL GEOLOGY

Previous Work

Numerous scientists have focused their attention on the Cibao Valley and have studied the rich molluscan localities of Miocene age on the Yaque del Norte River and its tributaries, the Mao, Amina, and Cana (Chapeton). The igneous and metamorphic rocks of the Central Mountain Range, bearing varying amounts of iron, copper, nickel, and gold, have been mined since the pre-Columbian period. A number of naturalists and engineers including Courtney

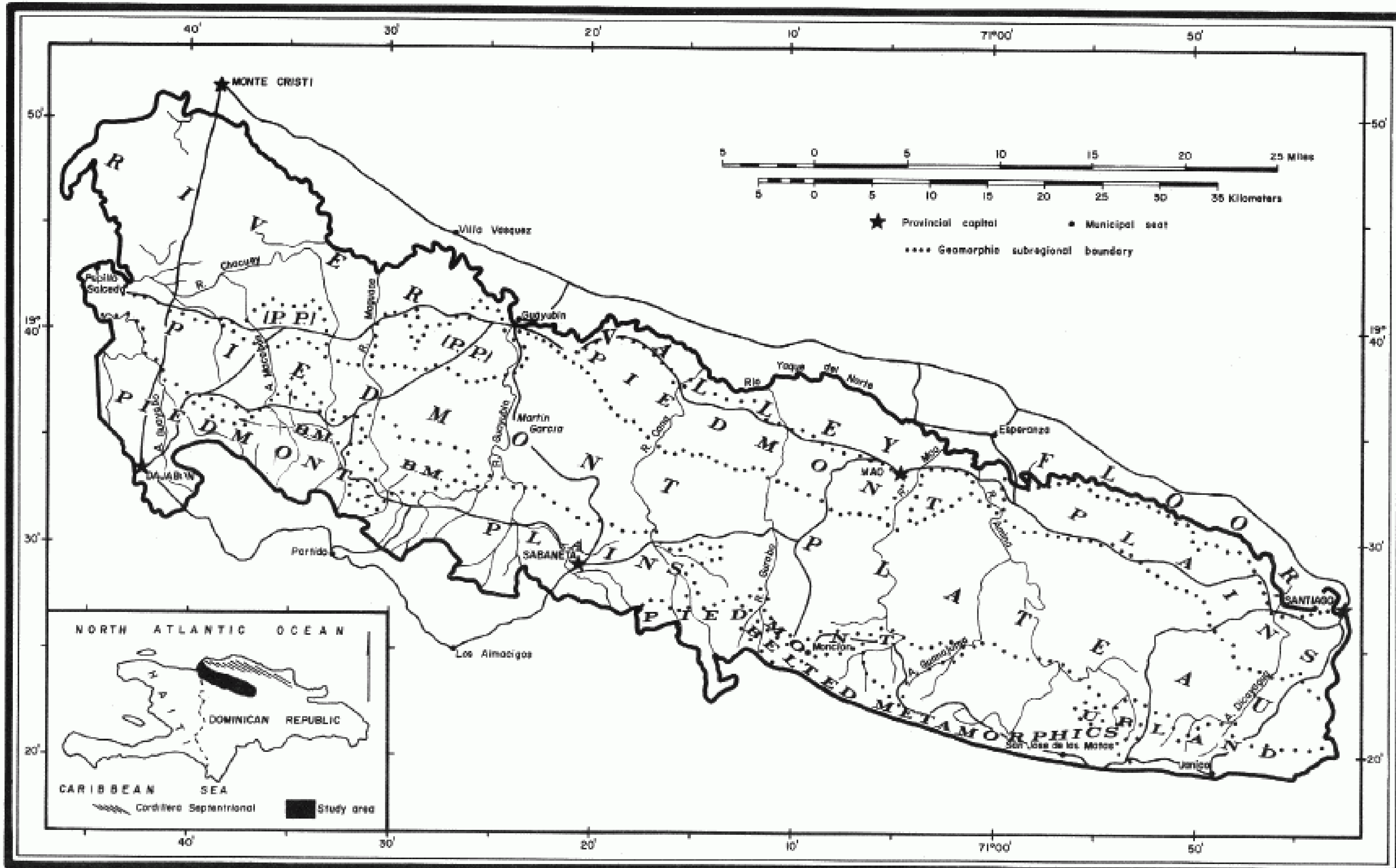


Figure 5. Map showing morphologic units in northwestern Dominican Republic.

(1860), Hazard (1873), and Garrison (1905, 1906, 1907) have written descriptive commentaries regarding the mineral resources of the Cordillera Central; however, no large-scale surface geological or morphological maps have been published of the study area. The most detailed reports found in a search of the literature are faunal descriptions of Miocene formations.

T.S. Heneken (1853) published a brief geologic description of the study region, listed faunas and included a geologic sketch map of the western Cibao. The reports of Gabb (1871, 1872, 1873, and 1881) are comprehensive descriptive works on the geology of the country but are mainly of historical interest. Maury's (1917a-b, 1918, 1919) studies provide the very basis for defining formations within the Miocene. The publication of Vaughan *et al.*, (1921) contains a wealth of information on the Tertiary rocks; however, few metasedimentary and plutonic igneous rocks are described or type localities cited between Sabaneta and Dajabon. The Bermudez (1949) study is the most recent comprehensive paleontological reference on the Miocene and covers the eastern portion of the study area. Weyl (1948) presents an accurate, small-scale regional description of the metamorphic and igneous rocks found along the southern flank of the area. Unfortunately, his maps are so small-scale that the reader's interpretation is sometimes liable to question.

Photogeologic mapping by Guerra Peña (1954) covers the western Cibao at a scale of 1:20,000, but stratigraphic boundaries drawn are of limited value because the units remain undefined. Furthermore, it appears that no correlative field investigation was undertaken to substantiate geologic structures inferred from photo interpretation. The geologic and geomorphic maps of the OAS National Resources Survey (Anonymous, 1967), published at the respective 1:250,000 and 1:500,000 scales, appear from their legends to have based mapping units on the Guerra Peña photogeologic study within the western Cibao. This may partially explain the significant discrepancies that exist between the OAS report and the writer's findings for the Moncion-Dajabon region.

Recent work by the Caribbean Research Project of Princeton University adds a wealth of detailed information to the hitherto little known geology of the Cordillera Central. The reports of Bowin (1966) and Palmer (1963), covering areas to the east and southeast respectively, have enabled the writer to identify and extend westward metasedimentary, volcanic and metavolcanic rock units found within the Sabaneta-Dajabon area.

During the course of the 1966 field season, a semi-reconnaissance geological field program was being carried out for the Dominican government by a group of Japanese scientists in the Central Mountain Range from Moncion to Dajabon.

Stratigraphy and Lithologic Correlations

Plate I is a surficial geologic map of the study area at a 1:100,000 scale, and Plate II is a schematic interpretation of the geomorphology and stratigraphic sequence in the Linea Noroeste. In the stratigraphic chart lithologic units are keyed where possible with correlative geologic formation names used by earlier researchers in the Dominican Republic and Haiti. The pre-Miocene sequence of rocks was examined in the field and laboratory with the aid of H.C. Palmer. Thus, these units definitively represent westward extensions of similar rocks mapped by Bowin (1966) and Palmer (1963) in the Cordillera Central. It should be noted, however, that correlations made with the Miocene sediments are tentative due to the fact that paleontologists in the past have identified and described the member units on the basis of fauna and not lithology. Lithologic/paleontologic correlations of the Cercado and Mao Formations proved least difficult, since these units have diagnostic lithologic and landform assemblages. Most tentative was keying out Gurabo Formation lithologies with corresponding faunal zones of Vaughan *et al.* (1921, pp. 69-73). Quaternary non-marine unconsolidated sediments were identified with units mapped in northern Haiti by Woodring *et al.* (1924, pp. 255-257) and Butterlin (1954, pp. 168, 170), and indexed with units described by Maury (1917b, pp. 444-447), Bermudez (1949, pp. 8, 17) and Vaughan *et al.* (1921, p. 175) for the western Cibao.

Type localities are given for each map unit by indicating the UTM grid coordinates found on the AMS Series E733 Dominican Republic topographic maps. The chart in Plate II also illustrates interrelationship between geology and surface morphology at the regional and sub-regional levels. Approximate positions on the geologic time scale are given for all map units.

General Geomorphology

A belt of hills found along the southern base of the study area is underlain by the metavolcanic Duarte and metasedimentary Amina Formations. According to H.C. Palmer (personal communication, 1969), these are considered the oldest rocks in the Linea Noroeste map area. Belted metamorphics cover a broad area in the southeast, but their extensions westward are confined to scattered, isolated en echelon residual knolls and maturely dissected hills.

North of the metamorphic zone lies the piedmont region. In the southeast early Miocene (Yaque Group) sedimentary rocks rest unconformably with depositional contact upon the Amina schist. The basal Miocene conglomerate member, which is quite resistant to weathering, underlies a piedmont upland subregion characterized by broad rounded ridges that rise in elevation to the south.

The three major Lower, Middle, and Upper Miocene formations underlying the piedmont plateau to the north are undisturbed, essentially horizontal or with a slight northward dip, and strike northwest-southeast. The southernmost unit, termed the Cercado Formation, overlies the Bulla Conglomerate with both a transitional and sharp conformal contact and forms a maturely dissected sandstone plateau. A marine shelf underlain by the lithified siltstones of the Gurabo Formation occupies a topographically higher elevation. This unit appears conformable with the underlying sandstone and grades into the overlying Mao limestone. The Upper Miocene Mao coraliferous limestone caps a series of genetically related cuestas, mesas and buttes that form the northern boundary of the piedmont plateau geomorphic region.

Two areas of piedmont plains are found within the mapped area. One is located north of the plateau and south of the Yaque River valley floor and consists of paleo-marine talus and a marine shelf of either Miocene and/or Pliocene age. The other piedmont plain is a relatively flat interior basin lying between the Cordillera Central and the limestone-capped ridge of Upper Miocene age in the southwestern portion of the study area. Unconsolidated fresh-water deposits grade from gravels and coarse sand at the mountain base to silts and clays near the northern subregional boundary. Earlier researchers, including Vaughan *et al.* (1921, p. 175) and Bermudez (1949, p. 8, 17) suggest that the unfossiliferous deposits are of Pliocene age and represent residual remnants of an original lag veneer that once covered the entire surface.

The river valley floor region, flanking the Yaque River from Santiago do los Caballeros to Monte Cristi, and its major tributaries, together with the Massacre River from Dajabon northward, consists of Pleistocene stream terraces, Recent floodplain and shoreline deposits.

BELTED METAMORPHICS

Geology

The belted metamorphic region found along the southern base of the study area covers map lithologic units 28-20, which correlate with the metavolcanic Duarte, metasedimentary Amina and Magua Formations, the partially recrystallized Moncion Limestone Member of the Tabera Group, and brecciated rocks of uncertain stratigraphic position. This geomorphic unit covers a broad area between San Jose de las Matas and Moncion. West of Sabaneta, these metamorphic hills appear in scattered and isolated localities as resistant knolls (Cerro Chino, 446586) and as a maturely dissected upland (Loma de los Garquises, 383622). Piedmonts flank the western metamorphic inliers and grade into unconsolidated fresh-water sediments of the piedmont plain.

The Duarte Formation was first studied by Bowin (1966) and included schistose and massive regionally-metamorphosed mafic volcanic rocks found from Santo Domingo to Jarabacoa. Palmer (1963) mapped the Duarte metavolcanics from Jarabacoa an additional 75 km west-northwestward to Moncion. Field study in this project area has shown that Duarte rocks extend along the regional strike some 65 km from Moncion to Dajabon. In this report the rocks typed as Duarte include massive and schistose greenstone, amphibolite, basic calcareous hornfels and amygdaloidal basalt. An attempt has been made in the text to differentiate facies changes within the formation map unit.

Duarte metavolcanics outcrop along and in places form the southern boundary of the map area. On the road from Sabaneta to Los Almacigos, greenschist facies rocks grade into higher metamorphic grade amphibolites. Contact between these two facies between Los Cercadillos and Agua Clara coincides with the southern map limit. From Agua Clara to Estancia Vieja, fine-grained laminated amphibolites flank the piedmont plain.

Hornblende tonalite intrudes greenschist and sub-greenschist facies Duarte rocks along the southern boundary of the mapped area, from El Pino (398509) to La Vigia. Perusal of geologic maps by Palmer (1963) and Bowin (1966) shows that similar intrusions exist to the east. Duarte country rocks flanking the Partido Pluton on the north and west are very fine-grained, generally schistose up to the contact, and hornfelsic in mineralogical assemblage. Intense shearing has occurred along the contact and throughout the metamorphic aureole. At one contact locality, sheared talcose greenschist is intensely crumpled into parallel layers and compressed into small folds.

Sericitic schist, which outcrops within the study area's belted metamorphic region, appears to be a westward extension of the Amina (Palmer, 1963) and Maimon (Bowin, 1966) Formations. This lithologic unit, termed Amina here, has been identified both in hand specimen and laboratory study as schist, consisting of varying proportions of chlorite, quartz, albite and epidote. A carryover diagnostic field characteristic from Palmer's area is the vein quartz pavement found on top of the bedrock. In one isolated locality west of La Gorra, laminated, contorted chert appears as a quartz-rich sub-unit of the Amina Formation. The writer has identified and mapped four distinct surface lithologies within the Amina Formation. Units 24 and 25 illustrate well the fact that the northern contact of Amina-related surficial materials is gradational and unconformable with the Bulla Conglomerate and Cercado sandstone of Early Miocene age.

Palmer's map shows Amina as an almost continuous outcrop from San Jose de las Matas to Moncion. Note that the southern contact of this unit is a normal fault which has placed Amina adjacent to pre-Miocene sediments. Westward, the fault apparently lies buried beneath piedmont alluvium, but approximately one km north of La Gorra in Dajabon Province, the Amina schist upland is flanked on the south by a belt of basaltic hills, either of sub-greenschist Duarte facies or equivalent to the basalt Rodeo Member of the Magua Formation (Palmer, personal communication, 1970). The lithologic contact is not seen but can be defined to within 50-100 m in the Maguaca River and shows a strongly preferred alignment along the inferred extension of the Amina Fault.

Northwest-southeast-trending inliers of Amina metasediments project through the piedmont plains. These monadnock-like features of resistant rock with their associated pediments are found at Cerro Chino (495595) located along the banks of the Guayubin River. Here, sheared schistose rock and quartzite lenses outcrop. Amina schist also underlies an extensive, maturely dissected upland north of La Gorra, called Loma de los Garquises, Los Altaderos (366674), and Loma de Tres Pied (326680).

The small area of chert, related compositionally and genetically to the Amina Formation and found west of La Gorra, appears as a structural anomaly. In thin section the chert is distinctly laminated and appears to be a very leucocratic variant of the Amina Formation. Quartz is completely recrystallized with a strongly metamorphic fabric. Iron-poor epidote and a chlorite grow along some of the foliation planes. The rock is much more metamorphosed than either basalts to the north or recrystallized limestone to the south. In degree of metamorphism it is like Amina schist and so is correlated as a sub-unit (Palmer, personal communication, 1970). Intense metamorphism evidenced by the chert may be the product of shearing stresses associated with faulting, which separated the Amina chert from the larger schist unit to the north and brought surficial lithologies related to Amina and Duarte (or equivalent basaltic Rodeo Member, Magua) Formations into contact (see cross section A-A', Plate I). An airphoto study of lineament tectonics suggests such an explanation.

Metamorphosed limestones, correlative with Palmer's Magua Formation and the Moncion

Limestone Member of the Tabera Group, were found in isolated outcrops juxtaposed with the Duarte and Amina units along the regional strike between the Guayubin and Massacre Rivers. The metalimestone typed as Magua Formation is massive, greenish-gray, intensely sheared and recrystallized with abundant calcite veining. At Cordero (435577) and La Gorra (367604), the unit is in contact with metavolcanics, and both units exhibit intense shearing with such structures as slickensides. Organic limestone lithology correlates with Palmer's (1963) Moncion unit and is buff, light-gray-colored, soluble limestone with some vein calcite. The western inlier at Canongo (164706) was identified by Vaughan *et al.* (1921, pp. 171-172) as Oligocene in age.

Two small units of pre-Oligocene brecciated metavolcanic and sedimentary rocks located between San Jose de las Matas and El Rubio have been transposed from Palmer's geologic map in order to extend the writer's present map area to include the Amina and Inoa Faults of the Oligocene graben, which serve as the boundary between the Cibao Valley and Cordillera Central geomorphic provinces. One outlier of the brecciated quartzo-feldspathic rock unit was identified and mapped west-northwest of Moncion. Description and stratigraphic interpretation of these units are covered by Palmer (1963, pp. 126-132) and hence are not included herein.

Soils

Soils developed within the belted metamorphic region have medium-textured surface and heavy subsoils with considerable coarse fragments of residual material on the surface and in the soil body. Profiles are shallow. The soil material exhibits a surprising degree of stickiness and plasticity when moist. The pH of these soils ranges from slightly acid to slightly alkaline. Surface colors are dark brown grading into a light yellowish-brown with increasing depth (Antonini *et al.*, 1967, p. 28).

Landforms

Two landform assemblages associated with the belted metamorphic region are a dissected upland and pediment surface. West of Sabaneta, deformation associated with contact metamorphism and/or faulting has produced highly sheared rock units of varied composition. Here, differential weathering, together with sheetwash and creep, have so etched the rock surfaces that areas underlain by the more resistant rocks are brought into relief as the less resistant are lowered. Local relief averages 40 m. The field relations are shown in the B-B' cross section in Plate I. An example of the etching process of erosion is seen in differential weathering of the Duarte and Amina units mapped north of La Gorra. Contorted chert forms topographically low portions; basaltic rocks and calc-silicate hornfels underlie the many small rocky knolls that give this area a characteristic microrelief not found elsewhere. Sparse vegetation and poor soil profile development facilitate effectiveness of creep and sheetwash as degradational processes in this semiarid environment (Antonini, 1968).

The land surface developed on the Amina Formation in the southeastern upland is more subdued and evidences less dissection and more moderate relative relief (25 m). Fluvial action and overland flow are important erosional agents, as indicated by the numerous intermittent and perennial streams that cross the area. Divides are generally flat-topped and broad. Palmer (1963, p. 14) has pointed out that the vein quartz accumulating on the soil surface produces a very effective shield against weathering. As a whole, the eastern metamorphic region exhibits a sub-mature fluvial landscape. The drainage pattern is basically subparallel, and most trunk streams appear to be consequent. Topographic texture is coarse in the southeast, where the drainage density is 9.2.[3] West of the Guayubin River, increased dissection and the occurrence of microrelief produce a finer topographic texture with a drainage density of 18.1.

PIEDMONT UPLAND

Geology

The piedmont upland is situated north of the southeastern belt of metamorphic hills underlain by Amina schist and is designated a sub-unit within the broad piedmont region mapped in Figure 5. The map lithologic unit 19 associated with this geomorphic subregion is identified within the stratigraphic sequence in Plate II and delineated on the geologic map in Plate I.

The Bulla Conglomerate basal member of the Lower Miocene Cercado Formation flanks belted metamorphic hills from Sabana Iglesia to Sabaneta. Vaughan *et al* (1921, pp. 66-67) named this unit after the village of that name found near the type section adjacent to the Mao River 6½ km northeast of Moncion. Examination of that outcrop shows yellow conglomerate interbedded with layers of sand. The lithology contains poorly sorted pebbles, cobbles, and subangular boulders of diorite, granite, schist and other rocks of the basal complex, ranging from 1 to 30 cm in diameter. To the south, Bulla Conglomerate rests unconformably with depositional contact upon the Amina schist. The northern boundary of the conglomerate is conformable and grades into the overlying Cercado sandstone. The C-C' geologic cross section in Plate I illustrates stratigraphic relations of this piedmont conglomerate.

Soils

Soils found on the piedmont upland surface are coarse-textured and contain a varied assortment of rounded igneous and metamorphic pebbles and cobbles. In places an indurated layer may be reached, but more commonly the profile is open and permeable. As a result, internal drainage is good. Openness of the soil juxtaposed with high local relief, however, gives rise to excessive external drainage. Texture grades from stony silt loams to coarse and fine sandy clay loam subsoils with a pH of slightly acid to neutral. Colors range from a dark reddish-brown to reddish-brown surface soil and from a yellowish-brown to light olive-brown subsoil (Antonini *et al.*, 1967, p. 28).

Landforms

Perusal of the surficial geologic map in Plate I shows that areas underlain by the Bulla Conglomerate exhibit a distinctive fan-shaped morphology. As one travels south toward the source area, increasingly angular fragments of igneous and metamorphic rocks are found. Presence of rounded to subangular cobbles and boulders of the basal complex indicates fluvial deposition and a high energy environment. Palmer (1963, p. 189) reports local presence of marine fossils and that at least part of the Bulla Conglomerate is marine. Apparently, the fan-glomeratic Bulla deposits represent the shoreline of north-central Hispaniola during Lower Miocene times.

Subjected to excessive sheetwash and moderate stream erosion, this piedmont upland exhibits a sub-maturely dissected land surface with 20% average slopes and 30-m high local relief. Divides show moderate reduction and average 100 m in width, but slopes continue to be smooth and rounded. Over larger outcrops, the drainage pattern is subparallel and higher-order streams are consequent. Topographic texture can be described as coarse with a drainage intensity of 10.9.

PIEDMONT PLATEAU

Geology

The piedmont plateau subregion is composed of three distinct formations of Miocene age. Formational names and descriptions first designated by Maury (1919) and later expanded upon by Vaughan *et al.* (1921, p. 65) are based upon detailed paleontological studies of fauna collected from exposures along isolated traverses of the Mao, Gurabo, Cana (Chapeton), and Yaguajal Rivers (see Maury, 1917b, pp. 425-444, and Vaughan *et al.*, 1921, pp. 65-75, 96-100, 113-153). The work of Bermudez (1949) is a more recent paleontological study of the Santiago-Moncion area and includes sketch maps (1:200,000) of the region showing faunal zones and sample locations, together with a listing and classification of fossil localities. On the basis of these published reports and the writer's field studies, the following correlations can be made between formation names, surface lithologies and related landforms. In the southeast the Lower Miocene Cercado Formation middle sandstone member underlies a maturely dissected plateau. Northward, the Cercado Formation grades conformably into the Middle Miocene Gurabo siltstone, where the land surface becomes a horizontal marine shelf and an undulating lowland. A series of limestone-capped cuestas, mesas and buttes striking west-northwest - east-southeast with a slight northward dip defines the northernmost plateau unit, which is underlain by the lower member of the Upper Miocene Mao Formation. Cross section D-D' in Plate I shows stratigraphic relationships found within the piedmont plateau subregion.

Perusal of the geologic map in Plate I indicates that the Cercado sandstone overlies the Bulla Conglomerate both with sharp and gradational conformable contacts. Maury (1917b, pp. 425-433) studied the formation by examining outcrops along the Mao River and typed the section at 798523. As a lithologic unit, sandstone of the Cercado Formation can be described as gray/blue fine calcareous sand with pockets and layers of indurated fossiliferous sandstone, which are profusely fossiliferous in many places. In the upper portion of this unit, lenses of fine sandstone and arenaceous siltstone occur. A diagnostic characteristic of Cercado lithology is the presence of highly indurated ellipsoidal lenses of fossiliferous sandstone averaging 1½ m in diameter. Small lentils averaging 8 cm are also found within the unit.

Maury (1917b) also typed the Middle Miocene Gurabo siltstone from outcrops along the entrenched meanders of the Gurabo River, from 703589 to 701597 at Gurabo Adentro, and along the Mao River south of the town of Cercado at 808547. Vaughan *et al.* (1921, pp. 69-73) extended the paleontological record by classifying outcrops of Gurabo siltstone eastward at the Guanajuma River ford (904550), Amina River ford (927537) and at the road cut west of La Canela (approximately 080545).

The writer has recognized and mapped two distinct lithologic units that tentatively correlate stratigraphically with the Gurabo Formation within the piedmont plateau subregion. These units, exposed from south to north, are the following:

(1) fossiliferous silt: pale olive, soft, somewhat argilliferous calcareous silt with or without macro-fossils. This surficial material overlies Maury's (1917b) Station 1 and Vaughan's *et al.* (1921, p. 69) Station 8546 at Gurabo Adentro. It is a major unit that characterizes much of the undulating lowland and marine shelf.

(2) fossiliferous siltstone and calcareous colluvium: light brown/yellow, soft, highly calcareous siltstone. Many beds contain calcareous concretions and/or are highly fossiliferous, but in some beds fossils are scarce or lacking. This unit contains colluvial calcareous deposits resulting from surface gravity flows of loose calcareous silt with scattered fossiliferous material from cuesta and mesa limestone cap rock. It correlates tentatively with Maury's (1917b) Zone P and Vaughan's *et al.* (1921) Station 8554 at 705615 on the Gurabo River.

The Upper Miocene Formation lower member was first identified by Gabb (1881, p. 151) and later studied by Maury (1917b), Vaughan *et al.* (1921, pp. 73-74) and Bermudez (1949, pp. 15-17). Conformable with the underlying Gurabo Formation, it forms the limestone cap rock for a series of cuestas and mesas that flank the Cibao Valley from Santiago to Pepillo Salcedo. Type locality given by Vaughan *et al.* (1921, p. 73) is for a section on the Mao River opposite Mao Adentro (815575). In this study it is termed the coraliferous limestone lithology and described as yellow/yellow-brown, hard, somewhat argillaceous limestone containing a great number of branching corals. Some arenaceous deposits occur in the basal portion. Where structure is essentially horizontal, mesas and buttes are the dominant landform. A slight dip produces a cuesta form.

Maury (1917b), Vaughan *et al.* (1921) and Bermudez (1949) recognized an upper conglomeratic member of the Mao Formation exposed in outcrops along the Gurabo and Cana Rivers north of the cuesta and thus outside the piedmont plateau subregion. Field studies in the mapped area show calcareous metacrystalline conglomerate and gravel, consisting of rounded and weathered pebble-cobble-size inclusions with a calcareous argillaceous matrix, interbedded and overlying the Mao reefal limestone as a cap rock of the butte 1½ km northwest of Los Quemados. The unit appears conformable at this location and can be considered of Upper Miocene age. Between Zamba and Martin Garcia, however, this surface lithology overlies fossiliferous silt on the marine shelf. According to Bermudez (1949, p. 16), this unconformity makes the outcrop Pliocene in age.

Soils

Soils developed within the piedmont plateau closely approximate the varied rock units and, in addition, show interaction of parent materials with climate and land surface. Calcareous sandstone plateau soils are shallow, often include a hardpan, and contain coarse weathered calcareous fragments in the profile. Typically medium-textured silt loams and fine sandy loams, they have fine sand and silt subsoils. As a result, the profile is still open but less permeable than piedmont upland soils. Erosion is excessive due to very high local relief which facilitates rapid external drainage. The pH of surface and subsoil ranges from 7.0 to 8.0 with considerable subsoil free lime occurring in the form of stains and nodules. Surface color varies from very dark gray-brown to dark yellow-brown. Subsoil colors are olive to pale olive and commonly include medium-sized distinct light gray and yellow mottles.

Fossiliferous siltstone soils are deep but moderately developed. They are typically medium-textured loams, silt loams, and silts with silty clay and clayey subsoils. Highly plastic and sticky when moist, they tend to suffer from poor internal drainage. Profiles may be stone-free or may contain some fossiliferous fragments. The pH of surface and subsurface ranges from 7.6 to 8.0; both soils contain considerable free lime. Surface color varies from dark brown to dark gray-brown; subsoils are olive to olive-brown. These soils occupy the largest area within the undulating lowland from Hundidera to Gurabo Adentro (Antonini *et al.*, 1967, p. 25). Westward from Las Caobas to Carbonera, the marine shelf is underlain by a variant of this soil. Here, pH's tend to be somewhat lower, and free lime is less pronounced. The brownish surface color is more strongly developed, but the subsoil takes on a definite grayish cast.

The colluvially-derived surficial lithologic unit 14 (Plate II) has shallow stony soils. Less than 183 cm thick (i.e., to hardpan or hard rock), they contain coarse calcareous fragments within the profile. Textures tend to be medium to coarse and pH remains high. Soils related to map unit 15 have intermixed and surficial gravel. A brownish surface color approximates the Gurabo siltstone soil, and subsoil colors of this unit are more apparent at the surface (Antonini *et al.*, 1967, pp. 25, 27).

Landforms

Land surfaces developed on the Cercado sandstone and Gurabo siltstone can be described as maturely dissected. On the sandstone plateau sloping, flat-topped ridges, locally called *cuchillos*, form the dominant landform and are often capped with indurated masses of sandstone. Divides averaging 50 m in width exhibit considerable reduction and, together with 46% slopes and a local relief of 35 m, produce a highly serrated topography. Land surface developed on the Gurabo siltstone is still maturely dissected but of low relief, moderate ruggedness and slope. This may be interpreted to mean that deep, steep-sided gullies are likely to be found within the undulating lowland and on the marine shelf. Ignoring height differences of the gully itself, local relief is generally less than 2 m. Slopes rarely exceed 10% (Antonini *et al.*, 1967, p. 33).

The Upper Miocene Mao limestone and polymictic conglomerate underlie the sub-maturely dissected, flat-lying mesa-butte complex and northward-dipping, maturely dissected cuestas. Sharply defined scarp-slope topography of the valley walls is accentuated by absence of vegetation, which directly facilitates action of runoff and channel erosion, important processes in cliff retreat. Scarp slopes exhibit high ruggedness, high relief, and high slopes. Local relief ranges from 3-20 m, and slopes from 10-60% (Antonini *et al.*, 1967, p. 33). Cuesta-mesa summit surfaces tend to be more subdued and are of modest slope, relief and ruggedness.

Throughout the piedmont plateau subregion, steep slopes, shallow medium-textured soils, and a semiarid climate produce the physical basis for excessive sheetwash and accelerated erosion during rainy seasons. Man, too, has been an active agent, aiding erosion with slash-and-burn farming and thus increasing area of exposed rock and surface soil to the infrequent torrential showers (Antonini, 1968).

Major trunk streams, such as the Yaque, Amina, Mao and Gurabo Rivers, are extended consequent streams initially developed when the region was a newly uplifted coastal plain. All are exotic entrenched perennial streams with courses extended northward from the Cordillera Central through the piedmont plateau. The Cañada de Tonico, a dry wash tributary of the Amina River, represents more recent stream development. This cyclical subsequent stream has developed on the belt of weaker rocks of fossiliferous silt underlying the undulating lowland.

Drainage pattern of most lower-order streams is dendritic. Topographic texture is finest on the sandstone surface with drainage density of 15.1. The siltstone plain (D=9.6) and limestone belt (D=4.5) reflect correspondingly reduced local relief on the undulating lowland and dense, forest-covered Zamba Hills mesa-cuesta complex.

PIEDMONT PLAINS

Geology

Two geographically and lithologically distinct piedmont plains defined within the mapped area are underlain by Tertiary and Quaternary deposits and represent Quaternary erosion surfaces of marine and/or fluvial origin.

The piedmont plain, located between Santiago and Copey, is bounded on the south by the Mao limestone mesa-cuesta complex and on the north by the Yaque River valley floor. Field study of the upper member Upper Miocene Mao Formation type localities has enabled the writer to identify and map the following two lithologic units: (1) calcareous polymictic conglomerate and gravel (unit 12, Plate I); and (2) friable, gray calcareous polymictic silty sand and colluvium (unit 11, Plate I). Both lithologies contain cross bedding, and large macrofossils were found at a number of sample sites. Cross section E-E' in Plate I shows the stratigraphic relationship of map unit 12 with the Middle and Upper Miocene formations near the type locality. Note that north of Sierra Las Caobas, polymictic conglomerate/gravel rests unconformably on the Gurabo siltstone.

Semi-consolidated argillaceous calcareous silt on the lowland and marine shelf from Hundidera to the Haitian frontier also extends below the Zamba Hills to outcrop within the piedmont plain north of paleo-marine talus slopes. Fossiliferous silt lowlands, located adjacent to the polymictic fan-glomeratic sand hills, are covered with scattered loose, rounded, weathered pebbles-cobbles and few boulders of igneous-metamorphic composition. This is identified as map lithologic unit 15.

Gabb (1881, pp. 153-156) identified coarse-textured western interior piedmont plain deposits as Tertiary in age and correlative with gravels along the Mao River. Maury (1917b, p. 30) distinguished between superficial gravels of probable Quaternary age and Tertiary gravels within her Sabaneta-Rio Yaguajal section, which she considered the type locality for gravelly knolls of the western piedmont plain. Works of Vaughan *et al.* (1921, p. 175) and Bermudez (1949, p. 17) suggest that these deposits are Pliocene and may lie on the truncated surface of northward-dipping Miocene sandstone and clay. Studies by Woodring *et al* (1924, pp. 225, 356) and Wood (1963, pp. 23-24) on Haiti's north plain show that Quaternary non-marine sediments underlie an extensive area adjoining the writer's western piedmont map units. Air photo interpretation of the adjacent Haitian region indicates similarities in form and structure between adjoining lithologic and morphologic units.

Three separate surface lithologies have been identified and mapped within the southwest piedmont plain: (1) fine- and medium-textured deposits: yellow-red/yellow-brown, noncalcareous, predominantly unconsolidated sand, interstratified with silt and clay (unit 9, Plate I); (2) coarse-textured deposits: rounded to subangular, poorly weathered gravel, composed of varying amounts of metamorphic mafic volcanics, calcareous metasediments, sericitic schist and plutonic igneous rocks (unit 8, Plate I); and (3) surface gravel with calcareous and noncalcareous evaporites: same as unit 8 but with caliche deposits in the soil profile and/or on the surface (unit 10, Plate I).

Field evidence suggesting non-marine deposition is: (1) lack of fossils; (2) characteristic red color, indicating a widespread oxidizing environment; and (3) occurrence of clay galls in the graveliferous unit. Surface gravels on this piedmont plain are less weathered and present more angular faceted surfaces than polymictic gravels south of the Yaque valley floor. Cross section E-E' in Plate I shows stratigraphic position of these units toward their eastern limit, and F-F' illustrates considerable breadth of the piedmont plain in the west-central region of the mapped area.

Soils

Soils of the northern piedmont plain closely approximate those of similar parent materials and slopes located within the piedmont plateau adjoining this unit on the south. Southwestern piedmont plain soils exhibit a gradational change in physical properties from east to west. Near Sabaneta, they are dark brown medium-textured sandy loams with strong brown clayey loam subsoils. The pH ranges downward from 7.2 to 7.0, and there is occasional gravel in the profile. Because elevation declines to sea level and surface relief diminishes toward the west, this profile exhibits the effects of imperfect drainage. Subsoil texture is clay, and the pH rises to 8.0; the yellow-brown mottled color reflects poor drainage (Antonini *et al.*, 1967, p. 30a).

Landforms

Examination of the geologic map in Plate I shows that the polymictic conglomerate/gravel/sand upper member of the Mao Formation overlies extensive areas within the northern piedmont plain at localities aligned within the former littoral depositional zone. In all cases, their positions coincide with major breaks or passes in the Upper Miocene barrier reef. Morphology of these outcrops exhibits characteristic form of marine deltaic deposition, i.e., commonly wide and fan-shaped at the distal end but narrowing to achieve funnel form at the river mouth. Likewise, interfingering of terrigenous detritus, limey deposits of the reef complex, and beach sand, together with cross bedding, further support the contention of a mixed high-energy depositional environment.

Geographically associated with the fan-glomeratic/sand units of the littoral zone are long, linear, paleo-marine talus ridges underlain by fragmented loose limestone detritus in a calcareous silt matrix. Stratigraphically, this talus unit correlates with the fossiliferous siltstone and calcareous colluvium which underlie the cuesta slopes (unit 14, Plate I).

The second piedmont plain occupies the relatively flat interior basin between the Cordillera Central on the south and Zamba Hills on the north and stretches from Las Caobas to the Massacre River. The southern perimeter of this western plain consists of a series of piedmont fans extending several kilometers from the mountain front. Morphology and composition are due to the sudden change in gradient at the foot of the mountain, causing rapid deposition of coarser debris. Increasingly finer-textured deposits are found to the north on the piedmont plain. These are deep noncalcareous silts interstratified with sand and clay. West of the Guayubin River, several localities of surficial gravel with calcareous and noncalcareous evaporites are found, units normally found along dissected interfluves of dry washes. Calcium carbonate is deposited chemically in the solum in this semiarid environment. Concretionary masses and caliche develop close to the surface on this badlands topography.

A comparison of the two piedmont plains shows that the inner lowland has more of a subdued land surface; it is a region of moderate relief, slope and ruggedness. Drainage density readings for units 8 (D=10.4), 9 (D=5.2), 10 (D=7.1), 11 (D=9.9), and 12 (D=17.2) reflect this fact.

RIVER VALLEY FLOOR

Geology

Fluvial deposition characterizes the northernmost section of the map region. It is also associated with stream valley development along most of the Yaque River's major tributary streams and the Massacre River.

Fine-medium- and coarse-textured unconsolidated Recent floodplain deposits have been mapped, in addition to graveliferous, fine-medium-textured and bedrock deposits, which lie adjacent to the outer perimeter of the floodplains. Bedrock terraces may or may not have a thin veneer of alluvium on them. Essentially they represent remnant valley flats produced, in most instances, through lateral erosion by graded streams.

Recent and older fluvial deposits are found along the Yaque and entrenched Dicayagua, Amina, Guanajuma, Mao, Gurabo, Cana (Chapeton), Yaguajal, Guayubin, Aminilla, Chacuey, Maguaca and Macabon Rivers. Recent fluvial deposition along the Massacre River has laid down very fine-textured sediment accumulations. This area, located north-northwest of Dajabon, is extremely level and is crossed by many distributaries which funnel the river's discharge into Manzanillo Bay. Recurrent annual flooding is characteristic of this zone. Test borings at six locations showed Recent stratified silts and clays to more than 20 m depth.

Soils

Young alluvial soils generally exhibit medium-to-coarse texture and in places may contain gravel and coarse fragments both on surface and scattered through the soil body. Profiles are deep and generally well drained internally, but external drainage is poor because of flooding. Massacre River floodplain soils are deep with silty clay textures and suffer from very poor drainage. Surface colors vary from dark brown to dark gray-brown, and subsoil colors from olive gray and yellow-brown to dark gray-brown and dark yellow-brown (Antonini *et al.*, 1967, pp. 29-30). The pH is normally slightly alkaline-to-slightly acid depending on sediment source area and local climate. In the Yaque delta area, however, increasingly poor drainage westward and a high rate of evaporation facilitate accumulation of excess salts in soils adjoining the mangrove swamps and brackish water lagoons that lie astride the far northwestern boundary.

Soils developed on older graveliferous alluvial terraces are similar to coarse-textured piedmont plains soils. Bedrock terrace soil genesis depends largely upon residual parent material.

Landforms

Post-Miocene faulting and folding brought the Cordillera Septentrional into existence to the north. This regional structural change diverted stream flow of the Yaque River west along a course of least resistant rocks. Drainage at that time became subsequent and followed regional geologic strike. The Yaque River was thus diverted west at Santiago and succeeded in capturing discharge from the Amina, Mao, Gurabo, Cana, Guayubin, Maguaca and Chacuey Rivers. Since the Cordillera uplift, the Yaque River system has deposited materials that have weathered into distinct morphologic units: (1) stream terraces; (2) Recent floodplain; and (3) a river delta.

Active fluvial deposition is occurring on the Yaque River floodplain (northern rim of the map region). West of the Guayubin River, where fluvial deposition exceeds rate of removal, the Yaque River has built a large delta extending westward to Manzanillo Bay. Prior to the later 19th century, the Yaque River shifted its meandering channel periodically within the delta. Canalization of the Yaque west of Guayubin in 1885 regulated stream flow, aligned the river's discharge through a major channel along the extreme northern boundary of the study region, and succeeded in draining the old oxbow lakes and swamp land stretching from the Maguaca River to Manzanillo Bay (Antonini, 1968).

SUMMARY

Surficial geology and morphology have been mapped in 2660 square km of the Dominican Republic: along the northern flank of the Cordillera Central and within the western Cibao Valley from Santiago de los Caballeros to the Haitian frontier. The region contains metavolcanic, metasedimentary and sedimentary rocks, in addition to unconsolidated alluvial sediments.

Originally a coastal plain during the Miocene epoch, post-Miocene faulting and folding brought the Cordillera Septentrional into existence to the north. This regional structural change transformed the area into an interior piedmont and montane upland now remote from the sea. Geologic structure parallels the northwest-southeast orientation of the Cordillera Central's crystalline basement, which lies to the south. Major physiographic units and their subregions mapped are: (1) belted metamorphics; (2) the piedmont, consisting of an upland, plateau and plains surfaces; and (3) river valley floors.

A belt of hills found along the southern base of the study area is underlain by metavolcanic and metasedimentary lithologic units considered to be the oldest rocks in the Linea Noroeste map area. Belted metamorphics cover a broad sub-maturely dissected area in the southeast, but their extensions westward are confined to scattered, isolated en echelon residual knolls and maturely dissected hills. Soil profiles are shallow and contain considerable coarse rock fragments.

North of the metamorphic zone lies the piedmont region. In the southeast Early Miocene (Yaque Group) sedimentary rocks rest unconformably with depositional contact upon the Amina schist. The Miocene basal conglomerate is quite resistant to weathering and has produced a broad, rounded and ridged piedmont upland that rises in elevation to the south. Soils devveloped on the country rock are coarse-textured and absorb moisture readily during the rainy seasons. High infiltration and runoff are characteristic features.

The three major Lower, Middle, and Upper Miocene formations underlying the piedmont plateau to the north are undisturbed, essentially horizontal or with a slight northward dip, and strike northwest-southeast. The southernmost unit, the Cercado Formation, overlies the Bulla Conglomerate with both transitional and sharp conformal contacts and forms a maturely dissected sandstone plateau. Flat-topped ridges, locally called *cuchillos*, form the dominant landform. Steep slopes and shallow medium-textured soils facilitate excessive sheetwash and erosion. A topographically high marine shelf underlain by lithified Gurabo siltstones appears conformable with the underlying sandstone and grades into overlying Mao limestone. The land surface is still maturely dissected but of low relief and slope. Gullying is well developed in the deep medium- to fine-textured calcareous soils. Upper Miocene Mao coraliferous limestone and conglomerate cap the series of genetically related sub-maturely dissected cuestas, mesas and buttes which form the northern boundary of the piedmont plateau geomorphic subregion. Soils found here are shallow, medium- to coarse-textured and contain many limey rock fragments.

Two areas of piedmont plains are found within the mapped area. One is located north of the plateau and south of the Yaque River valley floor and consists of paleo-marine talus, marine deltaic deposits, and a marine shelf of either Miocene and/or Pliocene age. Soils of this northern plain approximate closely those with similar parent materials and slopes located within the piedmont plateau to the south. The other piedmont plain is a relatively flat interior basin lying between the Cordillera Central and limestone-capped ridge of Upper Miocene age in the southwestern portion of the study area. Unconsolidated fresh-water deposits grade from gravels and coarse sand at the mountain base to silts and clays near the northern subregional boundary. Field evidence and the work of prior investigators suggest that the unfossiliferous deposits are of Pliocene age and represent residual remnants of an original lag veneer that once covered the entire surface. The southwestern piedmont plain soils show gradational change in physical properties from east to west with increasing alkalinity, heavy subsoil texture, and imperfect drainage.

The river valley floor region flanking the Yaque River from Santiago de los Caballeros to Monte Cristi, and its major tributaries, together with the Massacre River from Dajabon northward, consists of Pleistocene stream terraces, Recent floodplain and shoreline deposits. Young alluvial floodplain soils have deep profiles and exhibit medium-to-coarse textures. The pH and drainage characteristics vary as a function of parent materials and local climate. Soils developed on the older graveliferous terraces are similar to coarse-textured piedmont soils and bedrock terrace soil genesis depends largely upon residual parent material.

CONTENT FOOTNOTES

[1]The graphs used herein are taken from the study by Antonini *et al*. (1967, p. 36a). Note that the water balance curves given for selected stations in the northwest are based on the

Thornthewaite moisture budget accounting method which describes the relationship between actual and potential evapotranspiration and by doing so defines moisture deficiency and water surplus.

[2]Classification of land masses is based on geologic structure or lithology and closely follows the scheme developed by Strahler (1946, pp. 32-42). Accordingly, the belted metamorphic region includes areas of metamorphosed sedimentary and igneous rocks that have been folded and faulted in such a way as to produce a distinct but irregular elongate, subparallel ridge and valley alignment.

[3]Morphometric studies of fluvial landscape units were determined by selective sampling points. Texture grades were measured for areas covered by contour topographic maps using Smith's (1950, pp. 656-657) texture ratio. In areas where only aerial photographs were available, the Horton (1945) drainage density formula was used. Both texture and density measurements were used to describe the degree of stream dissection found in each landform region. Topographic texture is an expression of the spacing of the smallest drainage lines and is synonymous with Horton's "stream frequency" measured in terms of the number of stream channels per unit area. Smith's texture ratio is a logarithmic function of Horton's drainage density measurement. Thus, the two sets of values are correlative and can be keyed by their corresponding class interval values:

Topographic Texture		Drainage Density	
General Term	Numerical Values	General Term	Numerical Values
Coarse	<4.0	Low	<8.0
Medium	4.0 - 10.0	Medium	8.0 - 24.0
Fine	>10.0	High	>24.0

REFERENCES

Alpert, Leo, 1939, The climate of Hispaniola: Unpublished M.S. Thesis, Clark University.

Anonymous, 1967, Reconocimiento y evaluación de los recursos naturales de la República Dominicana: Washington, Pan American Union, Department of Economic Affairs.

Antonini, G.A., 1968, Processes and patterns of landscape change in the Linea Noroeste, Dominican Republic: Unpublished Ph.D. Dissertation, Columbia University.

________, L. Zobler, and N. Timofeeff, 1967, Natural environmental factors affecting potential agricultural productivity within selected arable areas of the Linea Noroeste region, Dominican Republic: A report of a special study team prepared for the Secretariat of Agriculture and the Instituto Nacional de Recursos Hidraúlicos (INDRHI) of the Dominican Government, New York.

Bermudez, P.J., 1949, Tertiary smaller foraminifera of the Dominican Republic: Cushman Lab. for Foram. Research, Spec. Publ. No. 25, p. 1-322.

Bowin, Carl, 1966, Geology of central Dominican Republic: a case history of part of an island arc: Geol. Soc. Amer. Memoir 98, p. 11-84.

Butterlin, Jacques, 1954, La géologie de la République d'Haiti et ses rapports avec celle des régions voisines: Publ. Com. 150^{e} Anniv. Indép. Républ. Haiti, Secr. Prés. Port-au-Prince, p. 1-446.

Courtney, W.S., 1860, The gold fields of St. Domingo, with a description of the agricultural, commercial, and other advantages of Dominica, A.P. Norton, New York.

Dunbar, C.O. and J. Rogers, 1957, Principles of Stratigraphy, John Wiley & Sons, Inc., New York. 356 p.

Gabb, W.M., 1871, Notes on the geology of Santo Domingo: Amer. Jour. Sci., 3rd Series, vol. 1, p. 252-255.

________, 1872, Description of some new genera of Mollusca: Acad. Nat. Sci., Philadelphia, Pa., Proc., p. 270-274.

________, 1873, On the Santo Domingo Miocene and its fossils: Amer. Phil. Soc., Proc., vol. 12, p. 571-573.

________, 1881, On the topography and geology of Santo Domingo: Amer. Phil. Soc., Trans., New Series, pt. 1, p. 48-259.

Garrison, F.L., 1905, Gold in Santo Domingo: Engineering & Mining Jour., vol. 79, p. 1128-1130.

________, 1906, The island of Santo Domingo: its natural resources and their prospective development: Cassier's Magazine, vol. 30, no. 5, p. 395-412.

________, 1907, Gold mining in Santo Domingo: Engineering & Mining Jour., vol. 84, p. 490-492.

Guerra Pena, F., 1954, Mapas fotogeologicos a escala 1:20,000: 113 sheets.

Hazard, Samuel, 1873, Santo Domingo, Past and Present, with a Glance at Haiti, Harper & Brothers, New York.

Heneken, T.S., 1853, On some Tertiary deposits in Santo Domingo, with notes on the fossil shells by J.C. Moore, and on the fossil corals by W. Lonsdale: Quart. Jour. Geol. Soc. of London, vol. 9, p. 115-134.

Horton, R.E., 1945, Erosional development of streams and their drainage basins: hydrophysical approach to quantitative morphology: Geol. Soc. Amer., Bull, vol. 56, p. 275-370.

Maury, C.J., 1917a, Santo Domingo type sections and fossils: Mollusca: Bull. Amer. Paleont., vol. 5, no. 29, pt. 1, p. 165-415.

________, 1917b, Santo Domingo type sections and fossils: stratigraphy: Bull. Amer. Paleont., vol. 5, no. 30, pt. 2, p. 419-459.

________, 1918, Santo Domingo paleontological explorations: Jour. Geol., vol. 26, no. 3, p. 224-228.

________, 1919, A proposal of two new Miocene formational names: Science, New Series, vol. 50, p. 591.

Palmer, H.C., 1963, Geology of the Moncion-Jarabacoa area, Dominican Republic: Unpublished Ph.D. Dissertation, Princeton University. 256 p.

Smith, G.K., 1950, Standards for grading texture of erosional topography: Amer. Jour. Sci., vol. 248, p. 655-668.

Strahler, A.N., 1946, Geomorphic terminology and classification of land masses: Jour. Geol., vol. 54, no. 1, p. 32-42.

U.S. Department of Agriculture, 1951, Soil Survey Manual, Government Printing Office, Washington, D.C.

Vaughan, T.W., W. Cooke, D.D. Condit, C.P. Ross, W.P. Woodring, and F.C. Calkins, 1921, A geological reconnaissance of the Dominican Republic, geological survey of the Dominican Republic: Memoirs, vol. 1, prepared by the U.S. Geol. Survey, Washington, D.C. 268 p.

Weyl, Richard, 1948, Geologia historia de la Cordillera Central de la Isla de Santo Domingo: Bol. Soc., Mex. de Geog. y Estad., vol. 66, p. 433-452.

Wood, H.A., 1963, Northern Haiti: Land, Land Use, and Settlement: University of Toronto Press, Toronto, Canada.

Woodring, W.P., J.S. Brown, and W.S. Burbank, 1924, Geology of the Republic of Haiti: Geol. Survey of the Republic of Haiti.