DEPARTMENT OF THE INTERIOR
U.S. GEOLOGICAL SURVEY

# Coal in Costa Rica - A progress report (1981)

by

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Open-File Report 85-369

Report prepared for the Agency for International Development,
U.S. Department of State

This report is preliminary and has not been reviewed for conformity with U.S. Geological Survey editorial standards and stratigraphic nomenclature.

1/ U.S. Geological Survey, Denver, CO
2/ Retired

1985

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ABSTRACT

Preliminary investigations performed to date in Costa Rica by the U.S. Geological Survey team indicate that:

Known coal beds are equal in thickness and areal persistence to beds that are minable in other parts of the world.

The coal is high enough in rank and grade to be used to generate electricity, and for other conversions such as gasification, and manufacture of fertilizers.

The available information does not allow a properly categorized, internationally comparable estimate of the coal resources of Costa Rica or of any area within the country.

Two complementary programs to obtain the geologic information needed for a basic understanding of the coal resource potential of Costa Rica are proposed:

A detailed geologic study in the Volio area of the southern Limón Basin to provide a basic understanding of the regional coal geology of south-eastern Costa Rica.

Geologic studies of the other known coal occurrences in Costa Rica to provide basic data needed for preliminary assessment of the coal resource potential of various areas in Costa Rica. Other little-known coal deposits may be as favorable as or more favorable than the coal of the Volio area.

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## INTRODUCTION

### Purpose of visit

Three years ago the Instituto Costarricense de Electricidad (ICE) started a program of investigation of the coal (and lignite) potential of Costa Rica, as a possible energy supplement to hydroelectricity in the country. The area of particular interest was in southeastern Coast Rica, where petroleum exploration has gone on spasmodically for years, and where coal (or lignite) deposits have long been reported. After three years of preliminary work, ICE felt that a technical review of progress to date and recommendations for the future was desirable. ICE approached the US Agency for International Development (AID) with a request for this type of review by coal experts. AID in turn asked the U.S. Geological Survey (USGS) to provide the techical assistance requested.

Ralph L. Miller (USGS Reston, Virginia) and Edwin R. Landis (USGS Denver, Colorado) were designated to compose the team to visit Costa Rica and carry on the work. Miller, a fuels geologist, had visited Costa Rica several times previously on other geologic assignments and had visited one of the known "lignite" deposits. Landis is widely experienced in coal geology both in the United States and in foreign countries.

### Program of work

Miller and Landis reviewed all available literature on "lignite" in Costa Rica before leaving the U.S. They then travelled to Costa Rica, arriving in San José on May 3, 1981. The following 2 days were spent conferring with officials and technicians of ICE, and reviewing maps, charts, and analyses of coal in the region of recent ICE investigations, herein after called the Volio area, after a small town in southeastern Costa Rica close to the Panamanian border.

On May 6th the USGS team and an ICE team left San José to visit the coal deposits of the Volio area. The ICE group for the field trip consisted of Hugo Taylor, a topographic engineer with many months of experience in the Volio area, Fernando Saenz, a geologist assigned to other projects but who had visited the Volio area, an assistant to Taylor, and two chauffeurs. An ICE geologist, Guillermo La Zama, who had done geologic work in the Volio area, was ill and could not join the party. The trip from San Jose to Volio took 5 hours.

During the next 3 days the group visited many coal outcrops in the drainage basin of the Rio Carbon de Volio, the area of the greatest number of known exposures of coal. The work was done on foot. The nearest approach possible by vehicles was about 1 1/2 km from the southernmost outcrop of coal. Coal samples were taken at four coal outcrops, and fossils were collected at two localities.

The group returned to San José on May 10. The following 3 days were spent in conferences with ICE officials and with preparation of a preliminary report.

After returning to their respective headquarters, Miller and Landis proceeded with the work of this final report, including a study of the reports, maps, charts, and analytical data acquired from ICE. Samples collected in the Volio area were submitted for analysis and study by laboratory experts. Conferences with these experts and other coal specialists, and results of the analytical work have been assimilated into this report.

## Acknowledgments

The work reviewed in this report could not have been accomplished without the enthusiastic cooperation and help of the ICE people with whom we worked. We express our warmest thanks to German Leandro, Chief of Geophysics Section, Hugo Taylor, Fernando Saenz, Agustin Rodrigues, and Luis Llach. On our field trip Efrain Quesada, geological assistant, and chauffeurs Orliden Lopez and German Vargas were always helpful over and beyond their assigned duties.

We regret that we did not have more opportunity to confer with Guillermo La Zama because of his illness. We are particularly indebted to Ing. Eugenio Odio G. for two conferences clarifying ICE's objectives in the coal program. We also gratefully acknowlege the valuable assistance of Heriberto Rodriguez, engineer, and Beverly Roper, secretary of the AID Mission to Costa Rica. Fossil identifications were made by L. W. Ward of the U.S. Geological Survey. Coal petrographic examinations were done by N. H. Bostick and C. S. Huestis of the U.S. Geological Survey.

# GEOLOGIC SETTING

## Geography

Costa Rica is near the southeastern end of the Central Americas chain. It is sandwiched between Nicaragua on the northwest and Panama on the southeast. It is the second smallest of the six Central American Countries, in both area and population, El Salvador being smaller, and Panama less populous. Compared with states of the United States, it is about the same size as South Carolina.

The topography of Costa Rica is dominated by backbone ranges of mountains from the northwest corner of the country near Lake Nicaragua to the southeast corner on the Panamanian border (fig. 1). The northwest part of this highland, known as the Cordillera de Guanacaste, is composed of an upland of

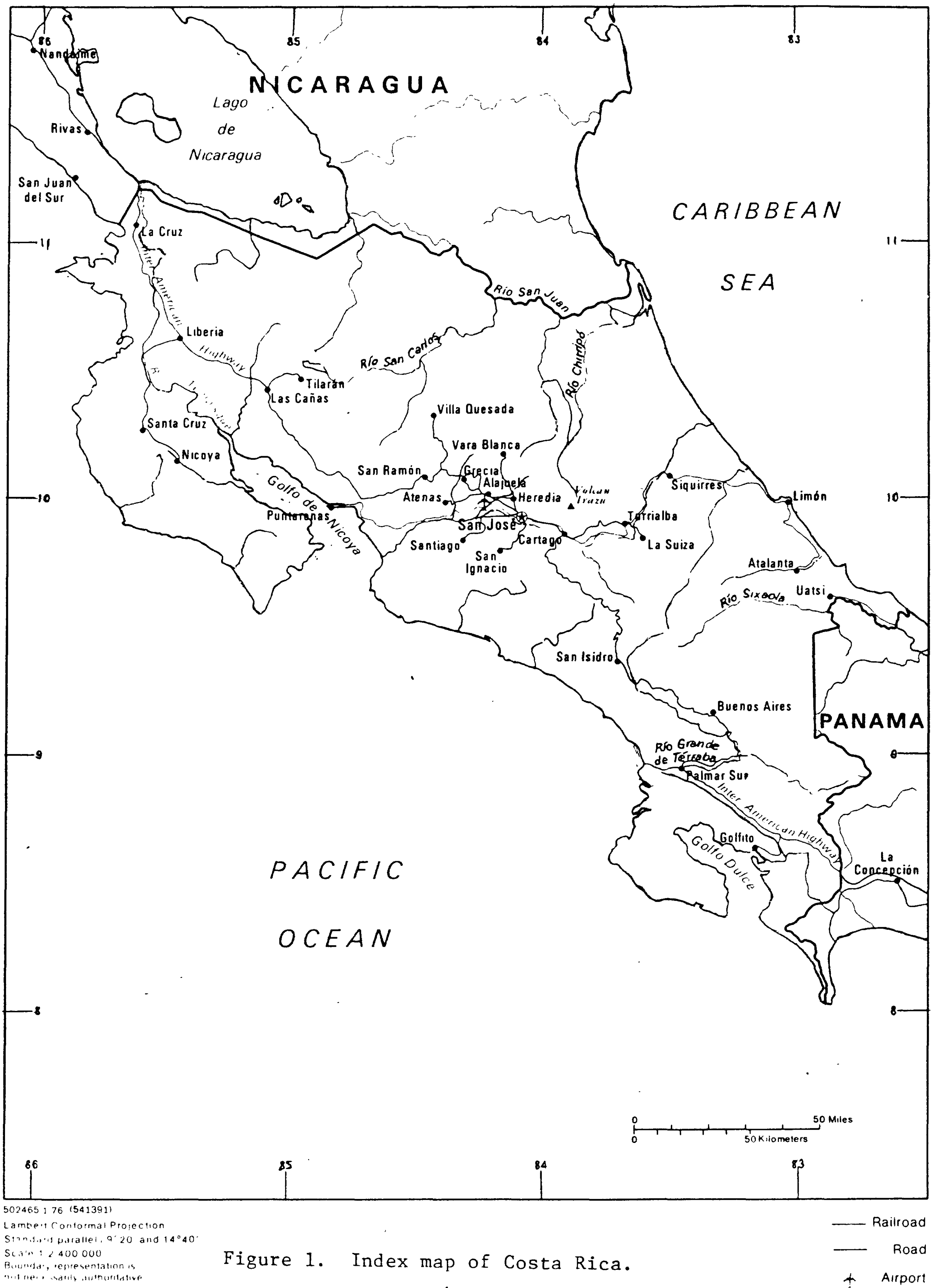


Figure 1. Index map of Costa Rica.

volcanic rocks surmounted by spectacular volcanoes, active and dormant. Those of large size are shown on the generalized geologic map of Costa Rica (fig. 2). The southeast part of the backbone ranges, named the Sierra de Tallamanca, is composed predominantly of intrusive igneous rocks.

The Central Highlands belt is flanked on the southwest by a narrow belt named the Pacific Lowlands, that borders the Pacific Ocean. This belt comprises the Nicoya Peninsula on the northwest, the Osa Peninsula on the southeast and additional near-coastal areas. The topography of this province is predominantly hilly and quite rugged, but altitudes are everywhere lower than the backbone ranges of the Central Highlands.

Bordering the Central Highlands on the northeast is another lowland area, the Limon Basin. Altitudes taper off gently and fairly regularly from the highlands foothills to the Caribbean coast. Most of the known coal deposits are in the Limon Basin. Those of principal importance in this investigation are in the extreme southeastern part of the basin near the Panamanian border. The location of these deposits is shown in figure 3.

## General geology

Central America is divided into two very different geologic provinces (Dengo, 1968), a northern and a southern. Geologically the northern province is a part of the North American Continent, with continental-type rocks as old as Paleozoic

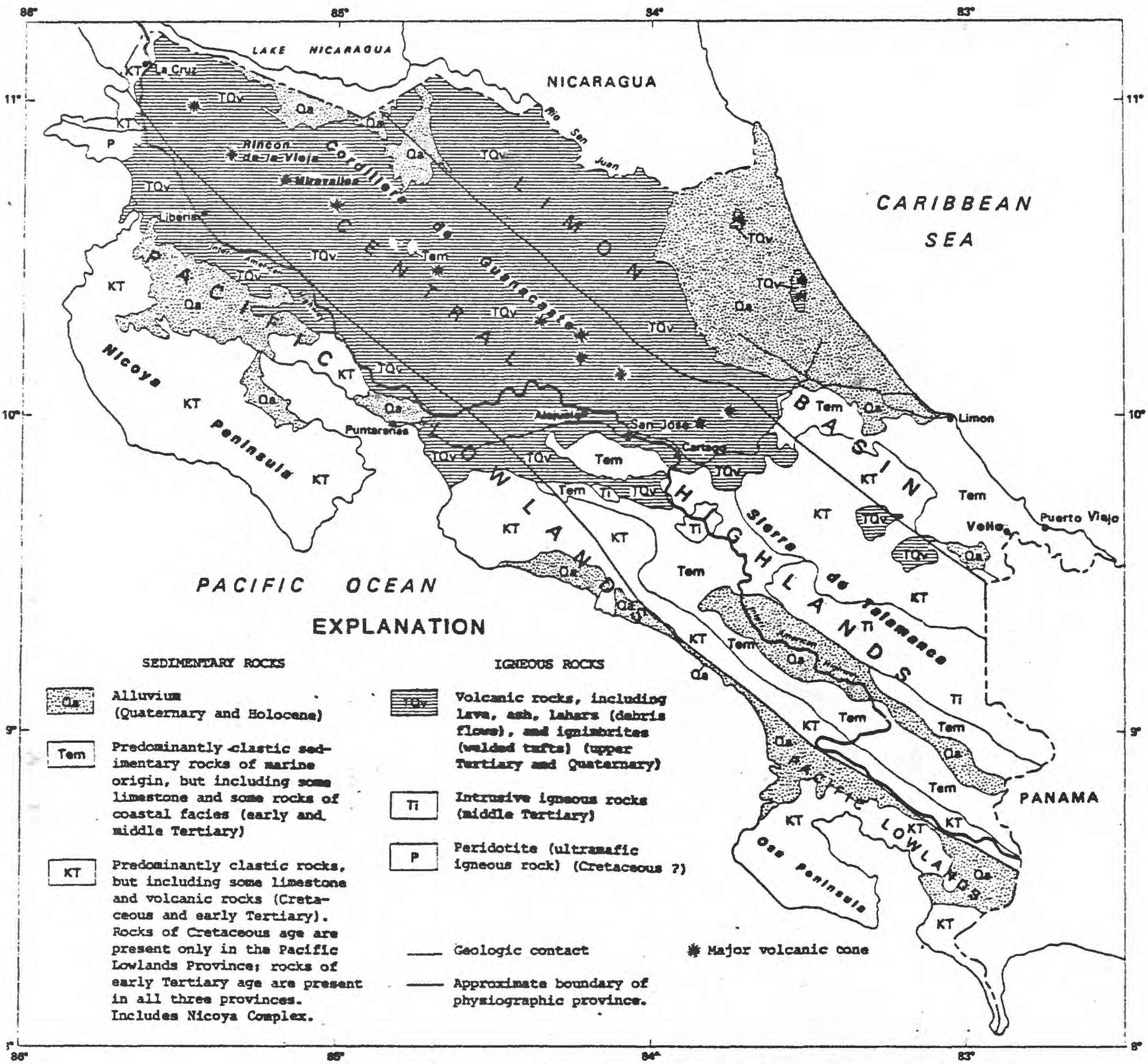


Figure 2. GENERALIZED GEOLOGIC MAP OF COSTA RICA

0 10 20 30 40 50
Miles

# Costa Rica


Figure 3. Known coal deposits in Costa Rica.

and some that are possibly older. The province comprises all of Guatemala, El Salvador, Honduras, and the northern part of Nicaragua. The southern province comprising southern Nicaragua, Costa Rica, and Panama is underlain by rocks having oceanic affinities similar to the rocks in the Caribbean and Pacific areas. The oldest rocks in the southern province are of Cretaceous age. The wide discrepancy in age of the older rocks of the two provinces may be seen in the standard chart of geologic time (fig. 4), in which the beginning of Paleozoic time is dated as 570 million years, whereas the beginning of Cretaceous time is but 138 million years ago. The rocks of Cretaceous age form a complex of volcanic and partly metamorphosed marine sedimentary beds which are still not well understood (Weyl, 1950, p. 116). They do not appear to have been deposited in an environment in which terrestrial peat-forming swamps could also have existed.

Worldwide, two great coal-forming periods existed, the Pennsylvanian-Permian at the end of the Paleozoic Era and the Cretaceous period at the end of the Mesozoic Era. In Costa Rica, no coal beds of either of those coal-bearing epochs have been found; one must look to the areas of sedimentary rocks of Tertiary age for coal or lignite. So far the coal that has been identified seems to be intercalated in sediments that are believed to be of Miocene age (Late Tertiary), though this does not preclude the possibility that future work might place some or all of the coal beds in rocks of Pliocene age.

The geologic map of Costa Rica shown in figure 2 has been generalized and reduced in size from the Geologic Map of Costa Rica (Dondoli, and others, 1968). As shown on this map, most of the country is blanketed by Tertiary and Quaternary volcanic rocks or by unconsolidated Quaternary deposits (alluvium). Beneath these blankets, it is not possible to tell without drilling what older rocks might be encountered. The rocks of Cretaceous age have been lumped with early Tertiary beds. Much remains to be learned about these rocks, but they consist largely

| Eon or Eonothem | Era or Erathem | Period or System | Subperiod or Subsystem | Epoch or Series | Age estimates[1] of boundaries in million years (m.y.) | Range |
|---|---|---|---|---|---|---|
| Phanerozoic Eon or Eonothem | Cenozoic Era or Erathem (Cz) | Quaternary Period or System (Q) | | Holocene Epoch or Series | 0.010 | |
| Phanerozoic Eon or Eonothem | Cenozoic Era or Erathem (Cz) | Quaternary Period or System (Q) | | Pleistocene Epoch or Series | 2 | (1.7-2.2) |
| Phanerozoic Eon or Eonothem | Cenozoic Era or Erathem (Cz) | Tertiary Period or System (T) | Neogene Subperiod or Subsystem (N) | Pliocene Epoch or Series | 5 | (4.9-5.3) |
| Phanerozoic Eon or Eonothem | Cenozoic Era or Erathem (Cz) | Tertiary Period or System (T) | Neogene Subperiod or Subsystem (N) | Miocene Epoch or Series | 24 | (23-26) |
| Phanerozoic Eon or Eonothem | Cenozoic Era or Erathem (Cz) | Tertiary Period or System (T) | Paleogene Subperiod or Subsystem (P€) | Oligocene Epoch or Series | 38 | (34-38) |
| Phanerozoic Eon or Eonothem | Cenozoic Era or Erathem (Cz) | Tertiary Period or System (T) | Paleogene Subperiod or Subsystem (P€) | Eocene Epoch or Series | 55 | (54-56) |
| Phanerozoic Eon or Eonothem | Cenozoic Era or Erathem (Cz) | Tertiary Period or System (T) | Paleogene Subperiod or Subsystem (P€) | Paleocene Epoch or Series | 63 | (63-66) |
| Phanerozoic Eon or Eonothem | Mesozoic Era or Erathem (Mz) | Cretaceous Period or System (K) | | Late Cretaceous Epoch or Upper Cretaceous Series | 96 | (95-97) |
| Phanerozoic Eon or Eonothem | Mesozoic Era or Erathem (Mz) | Cretaceous Period or System (K) | | Early Cretaceous Epoch or Lower Cretaceous Series | 138 | (135-141) |
| Phanerozoic Eon or Eonothem | Mesozoic Era or Erathem (Mz) | Jurassic Period or System (J) | | | 205 | (200-215) |
| Phanerozoic Eon or Eonothem | Mesozoic Era or Erathem (Mz) | Triassic Period or System (Ꞧ) | | | ~240 | |
| Phanerozoic Eon or Eonothem | Paleozoic Era or Erathem (Pz) | Permian Period or System (P) | | | 290 | (290-305) |
| Phanerozoic Eon or Eonothem | Paleozoic Era or Erathem (Pz) | Carboniferous Periods or Systems (C) | Pennsylvanian Period or System (ℙ) | | ~330 | |
| Phanerozoic Eon or Eonothem | Paleozoic Era or Erathem (Pz) | Carboniferous Periods or Systems (C) | Mississippian Period or System (M) | | 360 | (360-365) |
| Phanerozoic Eon or Eonothem | Paleozoic Era or Erathem (Pz) | Devonian Period or System (D) | | | 410 | (405-415) |
| Phanerozoic Eon or Eonothem | Paleozoic Era or Erathem (Pz) | Silurian Period or System (S) | | | 435 | (435-440) |
| Phanerozoic Eon or Eonothem | Paleozoic Era or Erathem (Pz) | Ordovician Period or System (O) | | | 500 | (495-510) |
| Phanerozoic Eon or Eonothem | Paleozoic Era or Erathem (Pz) | Cambrian Period or System (Є) | | | ~ 570[2] | |
| Proterozoic Eon or Eonothem (P) | Proterozoic Z (Z)[3] | | | | 800 | |
| Proterozoic Eon or Eonothem (P) | Proterozoic Y (Y)[3] | | | | 1,600 | |
| Proterozoic Eon or Eonothem (P) | Proterozoic X (X)[3] | | | | 2,500 | |
| Archean Eon or Eonothem (A) | Oldest known rocks in U. S. | | | | 3,600 | |

Subdivisions in use by the U. S. Geological Survey (and their map symbols)

[1] Ranges reflect uncertainties of isotopic and biostratigraphic age assignments. Age of boundaries not closely bracketed by existing data shown by ~ Decay constants and isotope ratios employed are cited in Steiger and Jager (1977).

[2] Rocks older than 570 m.y. also called Precambrian (p€), a time term without specific rank.

[3] Time terms without specific rank.

Geologic Names Committee, 1980 edition
U.S. Geological Survey

Figure 4. The geologic time scale.

if not entirely of old volcanic material and metamorphosed sediments (Nicoya Complex) in places overlain by sedimentary clastics and limestone of marine origin (Dengo, 1962b). No coal or lignite deposits are to be expected in these areas. According to Weyl (1980, p. 127-130) the late early Tertiary, and early late Tertiary (lower Miocene) deposits are likewise of marine origin but in the middle Miocene, the region was uplifted so that shallow coastal environments existed at times. These favored development of swamps and (or) lagoons in which plant material could accumulate, later to be buried, compressed, and transformed into coal beds. The known areas where Miocene rocks crop out and are large enough to be shown on the Geologic Map of Costa Rica (Dondoli and others) are labelled Tem on figure 2. It needs to be remembered, however, that geologically parts of Costa Rica are practically unexplored and unknown. It seems certain that future work will discover more areas of Miocene rocks in which coal beds might be present along with other sediments.

From late Miocene onward to the present, abundant and widespread volcanism has been dominant, particulary in the northwestern half of the country. In the area of the Cordillera de Talamanca, in the southeastern part of the country, intrusive igneous rocks were emplaced. This igneous activity has been accompanied by strong uplift of the Central Highlands. As the result of this uplift and consequent erosion, thick deposits of clastic sediments spread out over the subsiding Limón Basin. Weyl states (1980, p. 131) that the combined thickness of the Tertiary sediments and volcanics in the Limón Trough is more than 10,000 meters (32,800 feet). This great thickness of rock may not, however, be present now in any one place. The seismic and drilling records resulting from the past petroleum exploration in the Limón Basin would be of great value in further geologic studies in the area. The stratigraphy and structure of the

Basin could be more comprehensively and more accurately assessed, were these records available.

The broad outlines of the geologic structure of Costa Rica have been well described by Dengo (1962a) and are quoted in part below:

"Three major structural subdivisions (figs. 5 and 6) are significant. Their present tectonic and stratigraphic features are summarized.

"Outer arc. On the Pacific side of the orogen, a series of low ridges forms the following peninsulas: Santa Elena, Nicoya, Herradura, Osa, Burica, and Azuero (fig. 5). Structurally these peninsulas are related to several large en echelon complex anticlinal features, some of which show thrusting from the northeast (i.e, the central part of the Nicoya Peninsula).

"The area is characterized by a "basement" of volcanic, sedimentary, and intrusive rocks known as the Nicoya Complex, on which rests unconformably a series of Upper Cretaceous and Eocene marine sediments. The complex is best exposed in the Nicoya Peninsula. Locally there are small areas where marine sediments of Oligocene, Miocene, and Pliocene age have been deposited.

"Igneous activity in the outer arc was restricted to the older rocks during an early phase when the area was tectonically an embryonic mountain system characterized by a volcanic island arc.

"Inner arc. This is the principal structural arc of the orogen and lies northeast of the outer arc, on its concave side. The boundary between them is marked by a series of northwest-southeast trending faults, probably of transcurrent type.

"Several structural subdivisions are recognized within this arc. The major one is the Cordillera de Talamanca which extends throughout the length of the southern half of Costa Rica and continues into Panama with a

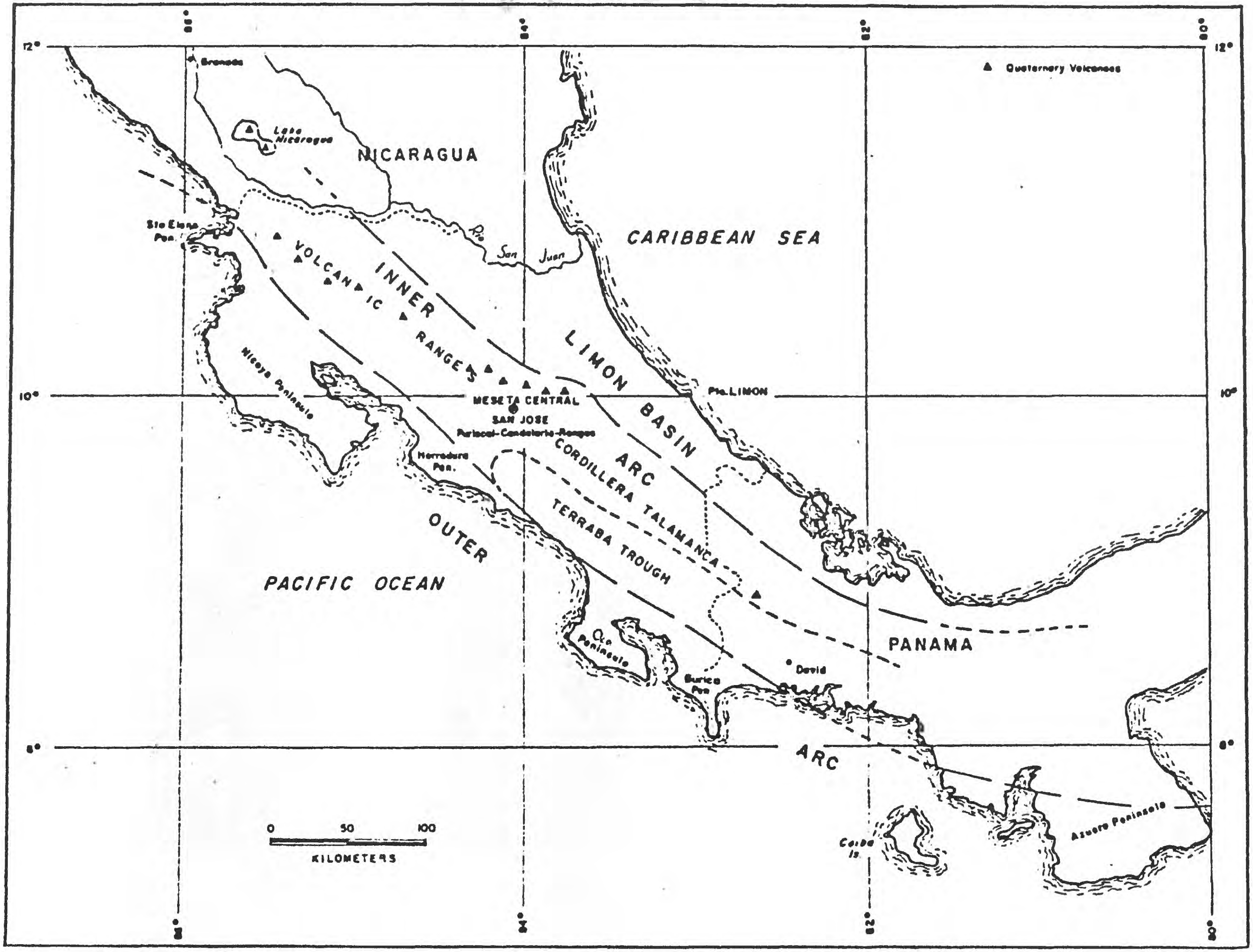


Figure 5. Structural subdivisions of Costa Rica and adjoining areas. (After Dengo, 1962a.)

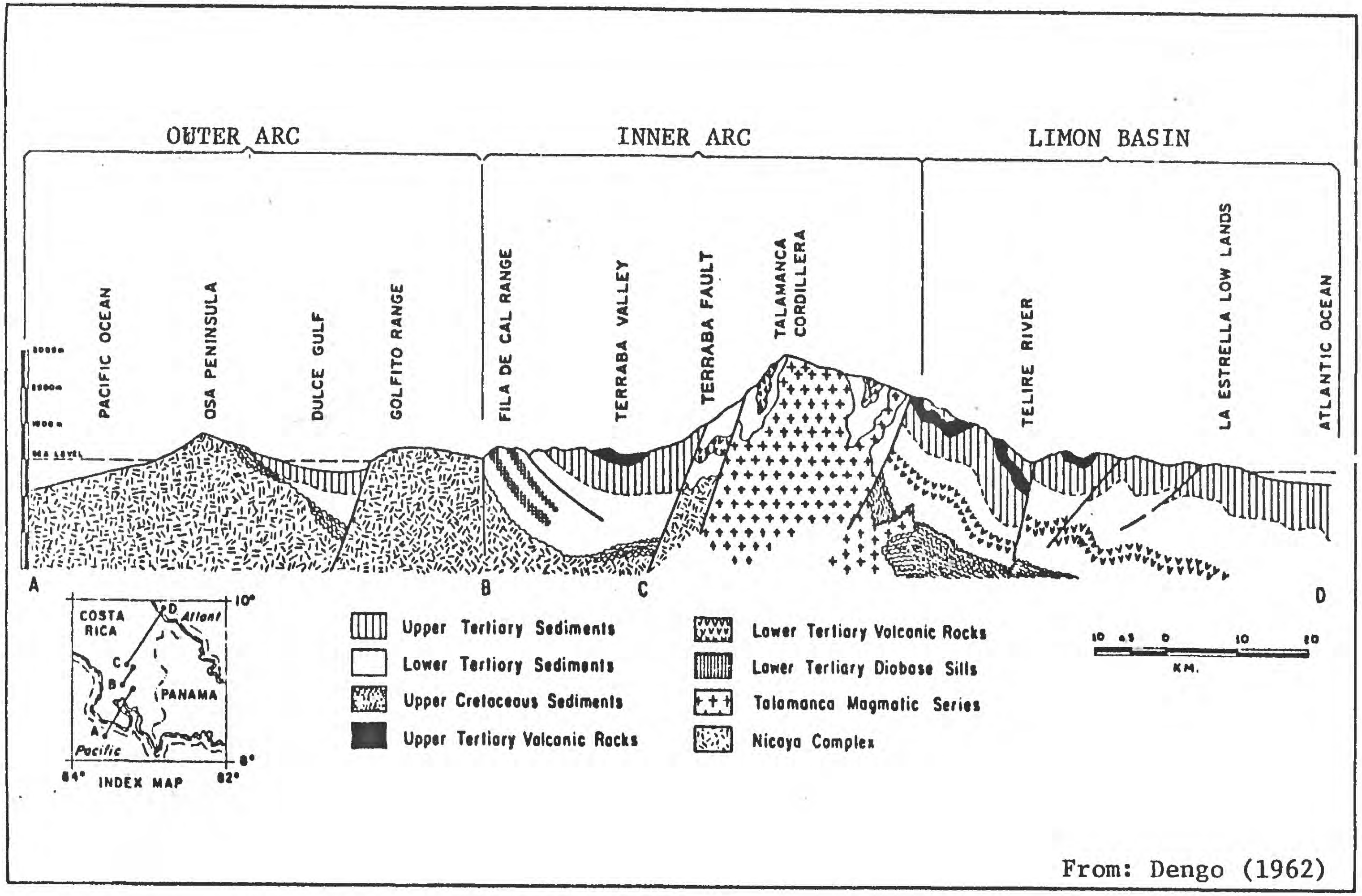


Figure 6. Schematic geologic section across southwestern Costa Rica.

general northwest trend. This cordillera is characterized by sedimentary rocks and lava flows. The marine sediments range from Eocene to lower Miocene. Upper Cretaceous rocks have not been identified in this area. The sediments have been intruded by several granodioritic stocks and basalt dikes.

"To the southwest of the cordillera the Terraba Trough extends southeast from San Isidro del General to the Chiriqui province of Panama. Marine sedimentary rocks in this trough range from Eocene to Miocene. The igneous rocks are characterized by diabase intrusions and a series of late Miocene-Pliocene volcanic rocks in the central part of the trough.

"The boundary between the Terraba Trough and the Cordillera de Talamanca is marked by subparallel northwest-southeast trending faults, down-thrown on the trough side. The boundary between the trough and the outer arc is marked by the La Faralla fault (fig. 6).

"Northward, the Cordillera de Talamanca branches into several east-west-trending ranges, the northernmost of which form the southern boundary with the Meseta Central (fig. 5).

"The northwestern part of the inner arc is formed by two main series of volcanic rocks that overlie folded Tertiary and Upper Cretaceous sedimentary rocks. These two series are the Aguacate volcanic rocks which form the ranges of Turrubares, Aguacate, Miramar, Abangares, and Tilarán, and the Quaternary volcanic rocks that form the Central Volcanic Range and Guanacaste Volcanic Range. Some Quaternary volcanoes are still active.

"The Meseta Central marks the boundary between the Cordillera de Talamanca to the southeast and the volcanic ranges to the northwest.

"Limón Basin. This sedimentary basin lies northeast and east of the inner arc, on its concave side. It is a geosynclinal basin which developed very rapidly, at times accompanied by strong volcanic activity and accumulating thick sediments. The sediments show facies changes within short distances and local unconformities caused by folding contemporaneous with deposition.

"The marine sediments range in age from Eocene to Pliocene. Upper Cretaceous sedimentary rocks probably underlie the Tertiary sediments because they have been found in neighboring areas in Panama, and in the Lari River in southeastern Costa Rica.

"Two major Tertiary sedimentary-tectonic facies may be recognized. An earlier one, characterized mostly by clastic deposition with associated carbonates, is followed by a great thickness of shales and sandstones ranging from Eocene to middle Miocene. A later facies from upper Miocene to Pliocene is characterized by a great thickness (in excess of 1700 m) of boulder conglomerates (Suretka Formation) and is undoubtedly related to rapid uplift of the Cordillera de Talamanca. In European terminology this corresponds to a molasse facies.

"Volcanic rocks are associated with the Eocene-lower Oligocene and upper Miocene-Pliocene sediments.

"The boundary between the Limón Basin and the Talamanca Cordillera is defined by a series of small ranges thrust to the northeast. Faulting and contemporaneous folding have affected rocks as young as Pliocene in the basin proper."

A major orogeny, which is most prominently represented in the Rocky Mountains region of the United States, began in Late Cretaceous time. In Costa Rica Cretaceous and pre-Cretaceous rocks along the Pacific Coast (outer arc of Dengo) and in the Central Cordillera (inner arc) were uplifted. This was followed by volcanism in Eocene time, concurrent with downwarping of the Limón Basin and a smaller basin, the Terraba Trough, paralleling the Pacific coast in southernmost Costa Rica. According to Dengo (1962a, p. 157), the flooded basins were connected with each other and with the Caribbean and the Pacific, and they persisted into late Oligocene time. There appears to have been a shallowing of the seaways in Oliogocene time, resulting in deposition of clastic sediments of lagoonal facies (Weyl, 1980, p. 127). This trend continued into the Miocene, when much of southern Costa Rica must have been above sea level, resulting in erosion of older deposits and development of a major unconformity (Weyl, p. 127). In middle Miocene, emergent and shallow marine environments prevailed with deposition of thick marine and continental sediments, including limestone offshore, and accumulation of abundant plant material in swamps and bogs in low-lying land areas. This appears to be the time when most if not all of the known coal beds of Costa Rica were formed by accumulation of peat in the near coastal swamps, later to be buried and metamorphosed to lignite or coal.

In late Miocene and Pliocene time, renewed uplift of the Central Cordillera resulted in accelerated erosion, and in deposition of coarse sediments shed off the flanks of the mountain ranges, to intertongue with marine sediments in the coastal regions. At the same time renewed volcanism spread ash falls and lavas over broad areas. This regimen persists to the present time.

Folding and faulting of the bedrock accompanied the late Tertiary-Holocene orogeny, resulting in moderate to steep dips of beds in most places, and numerous faults, large and small. Because of this structural complexity, careful geologic mapping is necessary to establish the relation and continuity of coal beds. In this endeavor, seismic exploration also provides assistance, especially in areas of poor bedrock exposures, or where recent lava flows and ash falls have buried the older rocks.

It appears from this brief resume of the historical geology of Costa Rica, that the coal beds were deposited in Miocene time, and areas where rocks of Miocene age are found are good places to look for coal beds.

## Limón Basin

As shown on figure 5, the Limón Basin makes up the eastern part of Costa Rica between the Central Highlands and the Caribbean Sea. In the southern part of the basin, sedimentary and volcanic rocks of early and late Tertiary age are present at or near the surface (fig. 6), and sedimentary rocks of Cretaceous age may be present beneath the Tertiary rocks (Dengo, 1962a, p. 138). In the northern part of the basin volcanic rocks of late Tertiary and Quaternary age cover the older sedimentary rocks except in small areas where the younger volcanic rocks have been removed by erosion.

The structure of the Limón Basin is still not completely understood despite several episodes of geologic mapping and geophysical studies in support of oil and gas exploration in the southern part of the basin (fig. 7). As many as 26 holes have been drilled in this area in search of oil and gas or for stratigraphic data, but this crucial information is not available to most geologists working in Costa Rica. Other factors contributing to the lack of detailed understanding of the structure of the Limón Basin are the lack of exposures over large areas, and conflicting interpretations of the stratigraphic sequence.

Figure 8 presents two slightly different stratigraphic columns representing the rock sequence in the Limón Basin. Both columns are from Weyl (1980, tables

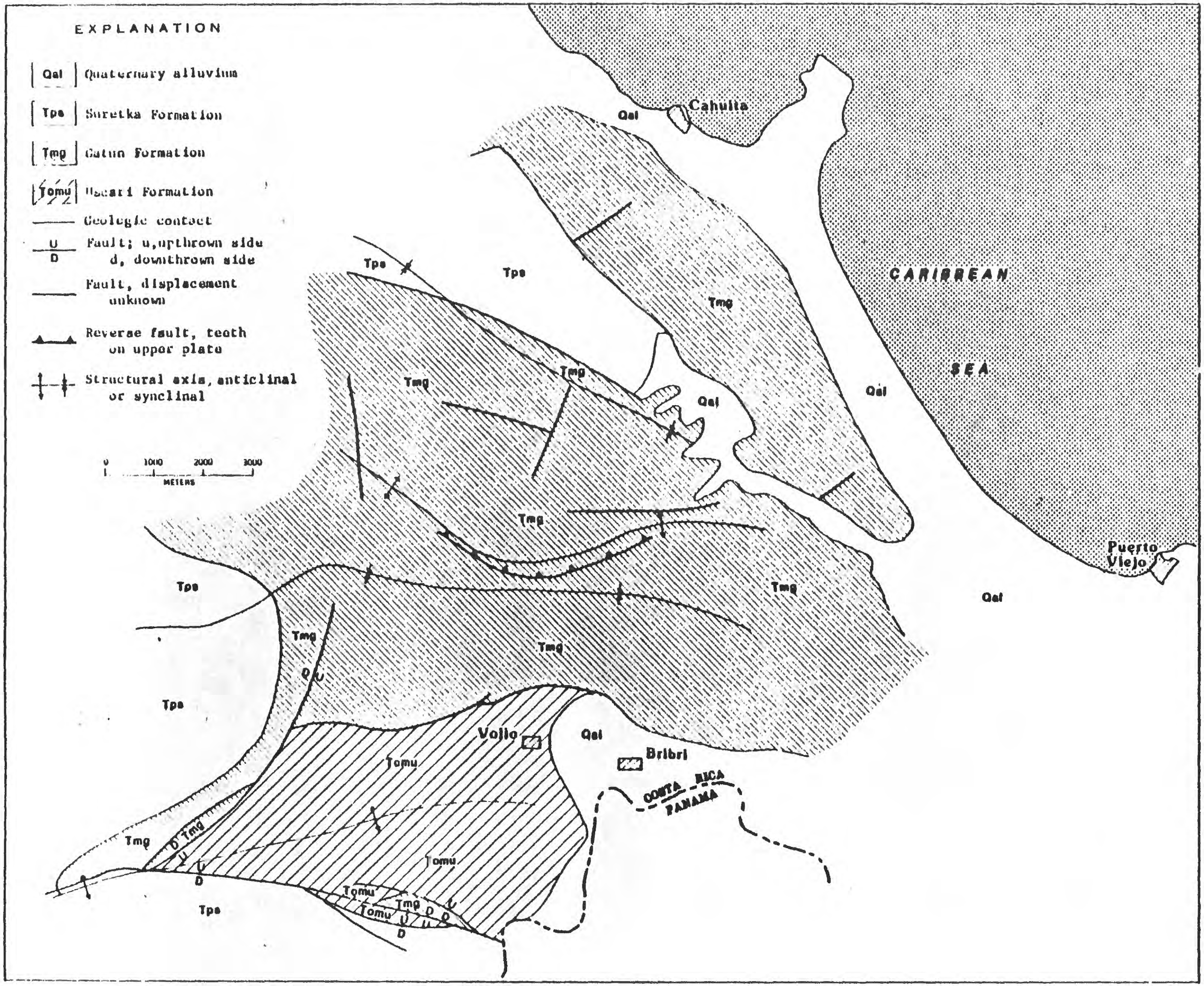


Figure 7. Generalized geology and structure of part of southern Limón Basin (modified from map by Instituto Costarricense de Electricidad).

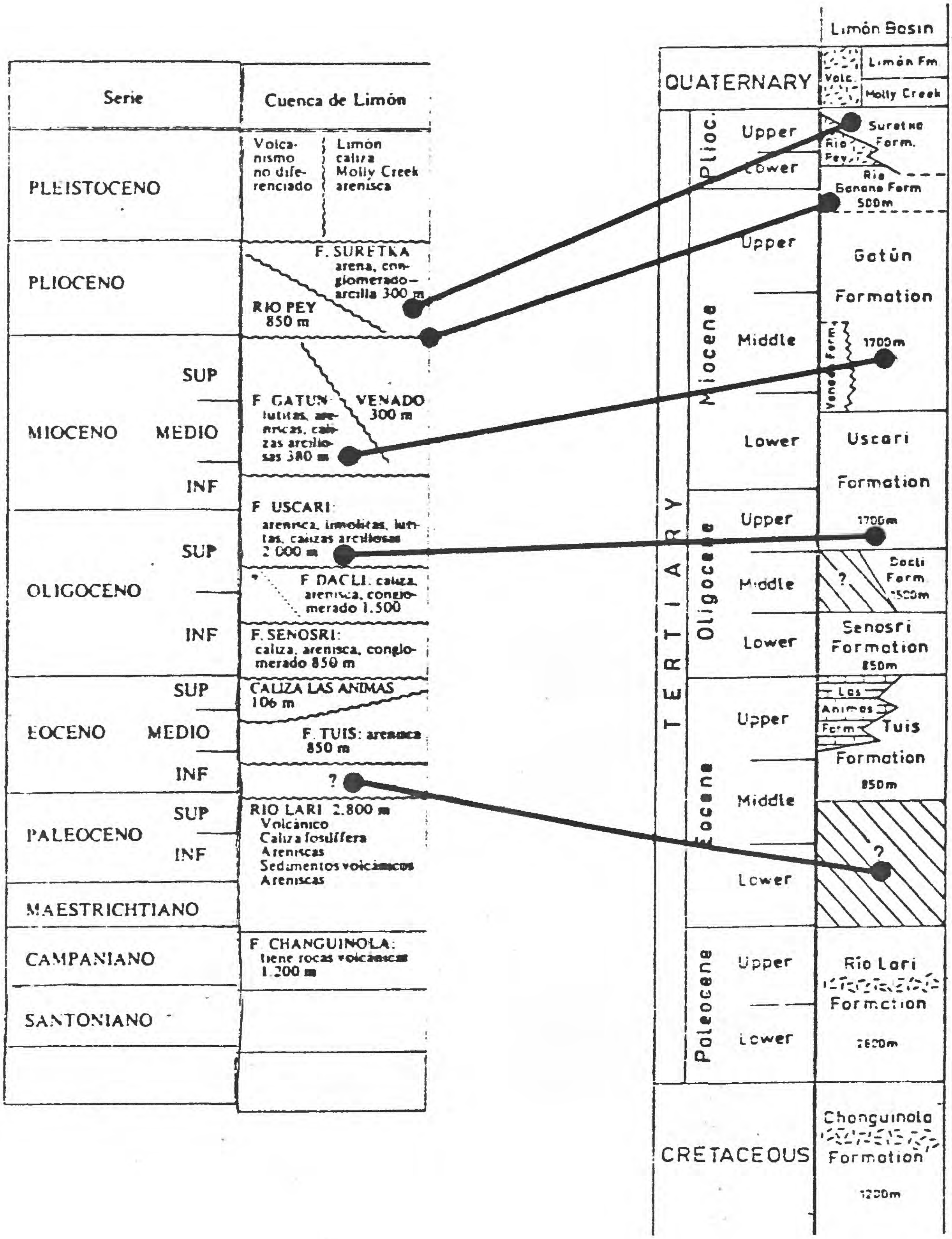


Figure 8. Stratigraphic columns for localities in the Limon Basin. (from Weyl, 1980, Tables 4a and 4b).

4a and 4b); the left column is attributed to an anonymously authored report, and the right column to unpublished data of Escalante and Fischer. The lines between columns connect points of possible stratigraphic discrepancy. Weyl (1980) does not state whether the columns are supposed to represent the rock sequence in the Limón Basin in general, or whether one or both of the columns represent smaller and separate parts of the basin. For the purpose of the present study, the major differences shown on figure 8 are the disparity in thickness of the Gatun Formation--380 m compared to 1,700 m--and the relationships of the Uscari, Venado, and Rio Banano Formations to the Gatun Formation.

## Volio area

The Volio area (fig. 9) is only part of the area underlain by potentially coal-bearing rocks in the southern Limón Basin. The area delineated on figure 9 does include most of the area in which recent work on coal occurrences has been done.

The Volio area is west of the narrow coastal plain between the towns of Cahuita and Puerto Viejo and west and northwest of the town of Bribrí and the Rio Sixaola, which here marks the Costa Rica-Panama boundary (fig. 9). The south part of the area is drained by the Rio Uatsi, the Rio Carbon de Volio, and other small tributaries of the Rio Sixaola. A graded and gravelled road connects Bribrí with the gravel coastal road between Cahuita and Puerto Viejo. A narrower graded road with gravel connects Volio with Bribrí. A railroad once paralleled the Rio Sixaola from Volio to near the mouth of the River and another railroad has been replaced by the coastal highway along the Caribbean.

The area of Quaternary alluvium in the southern part of the area (fig. 10) is nearly flat, as is the coastal plain to the east, but the areas of older rocks where the coal beds are present are generally characterized by sharp local

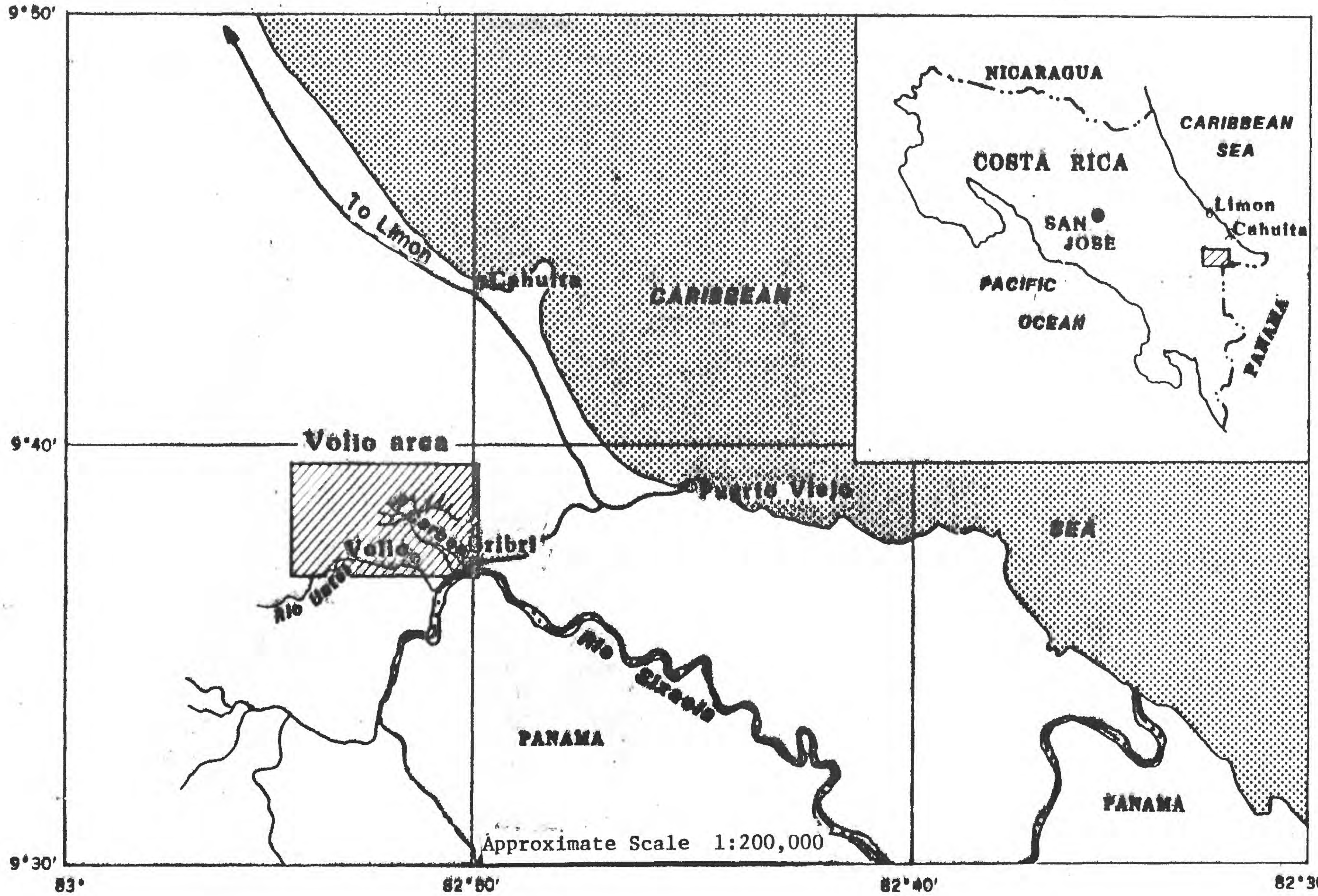


Figure 9. Index map of part of Costa Rica showing location of Volio area.

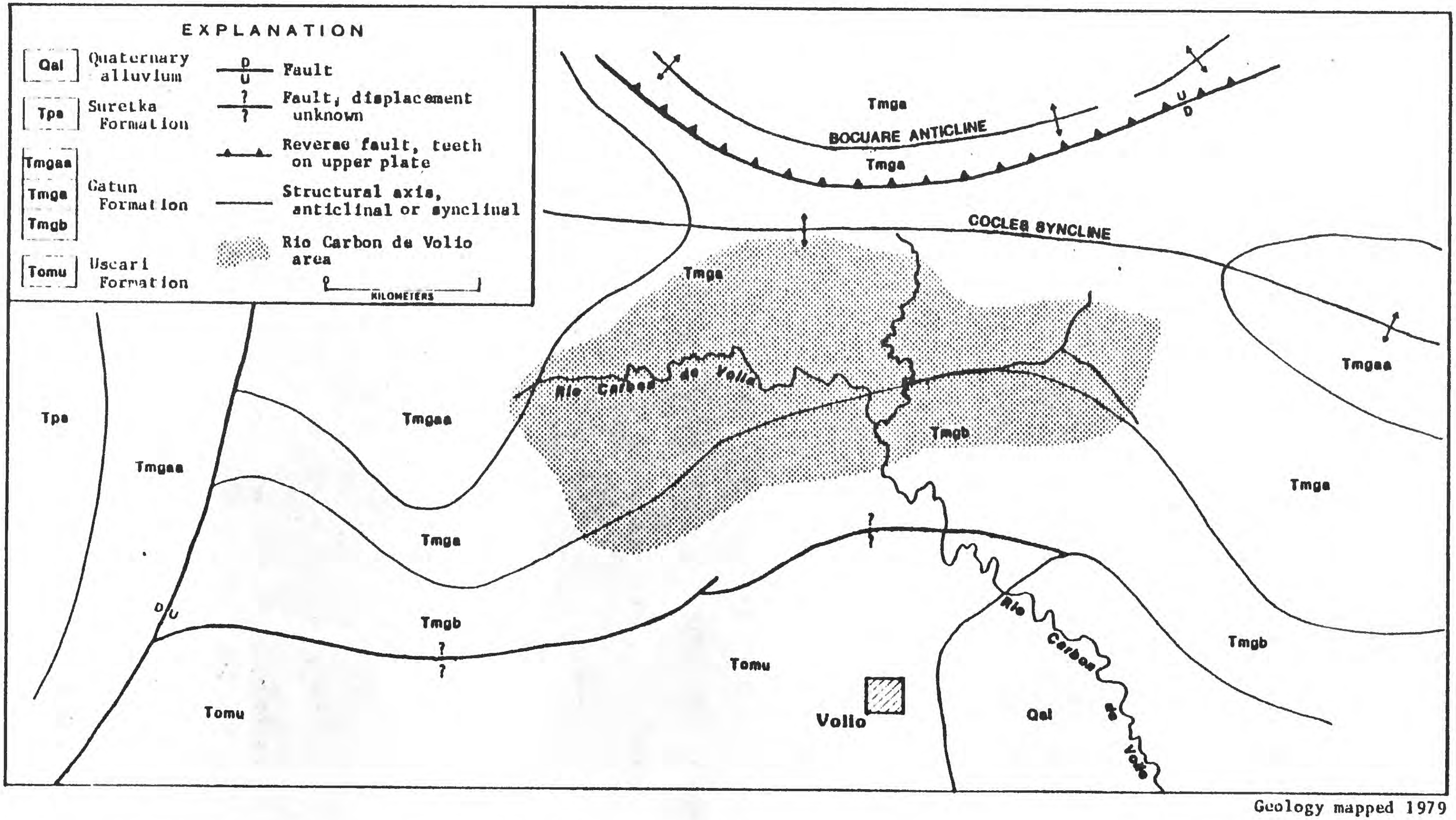


Figure 10. Geology and structure of the Volio area (adapted from Instituto Costarricense de Electricidad).

relief of as much as 300 m. The coals and associated rocks are exposed along narrow drainages at the base of very steep valley walls.

In the Volio areas as is shown on figure 10, the coal-bearing rock unit, the Gatun Formation of early, middle and late Miocene age--and early Pliocene(?) age (see Results of Present Study, Biostratigraphy)--overlies the Uscari Formation of late Oligocene and early Miocene age and is overlain by the Suretka Formation of Pliocene age. Both the upper and lower contacts of the Gatun are reportedly unconformable, though some differences of opinion apparently exist. The Uscari Formation consists mainly of fine-grained clastics of neritic (low tide to 600 ft) and pelagic (deep sea) origin (Weyl, 1980, p. 128), and the Suretka is dominated by sandstone and conglomerate of terrestrial origin. The Gatun Formation of epineritic (low tide to 120 ft) and paralic (near-coastal) origin (Weyl, 1980, p. 129) consists of fine- to medium-grained clastics, but also includes coal beds. Some carbonates are intercalated with the clastics. The Gatun has been subdivided into as many as three members (fig. 10). Some parts of the formation are of marine origin, and other parts nonmarine.

As previously mentioned (Dengo, 1962a, p. 138), the Tertiary rocks of the Limón Basin were subject to structural deformation both during deposition and by later folding and faulting. Most of the coal-bearing rocks of the Volio area are on the south flank of the large Cocles syncline (fig. 10) and consequently are regionally inclined to the north, but on the north edge of the area the Gatun Formation is cut by a thrust fault and is present across the axis of the Bocuare Anticline. The rocks in the drainage basin of the Rio Carbon de Volio generally strike nearly east and dip to the north at angles from 11° to 20°. Local reversals of dip and strike reflect local structures but do not radically affect the general structural situation.

## REVIEW OF PREVIOUS COAL INVESTIGATIONS

### Early studies

In the sections which follow, the word coal should be understood to also include lignite, which is the lowest rank of coal. In many places where coal has been reported in Central America, it has not been established whether the carbonaceous bed is lignite or of a higher rank of coal such as subbituminous. Bituminous coal is more to be desired, but lignite should not, however, be dismissed as too low in heat value to be economic. Lignite is being burned in some countries, especially for the generation of electricity, in ever-increasing amounts, even in a coal-rich country such as the United States.

Coal is easily recognized and easily sampled, and has been reported in many places in Central America. The earliest record we find in Central America is in the Proceedings of the Boston Society of Natural History for 1859-1861. At a meeting on December 5, 1860, Dr. C. T. Jackson of Boston exhibited specimens of coal from the Gulf of Chiriquí in western Panama, discovered by Dr. John Evans. Jackson stated that the coal "contains about forty per cent of bituminous matter, with nine per cent of ash; it is well adapted for steam engines, for the manufacture of gas, and for similar purposes, and, if existing in large quantity, will be of immense value to this region. Judging from the fossils which accompanied the specimens, such as *Cardium*, *Cerithium*, *Arca*, *Natica*, *Mytilus*, and other shells, this coal belongs to the upper Eocene period." At the next meeting of the Society two weeks later Jackson presented some fossil shells from the coal formation at Chiriquí, "which is of Eocene age and apparently equivalent to the Paris basin. The thickness of this coal is about 73 1/2 feet, of which 30 feet are so near together as to be worked in a single gallery. A broad belt of this coal extends through British Guiana and Costa Rica, the more southern portions having been examined by D'Orbigny, Darwin, Wheelwright and other French and English naturalists; the true coal series, however, has never been discovered in South America. This coal in quality is almost identical with cannel; in specimens analyzed from different localities, the carbon varied from 39 to 43 1/2 per cent, the gas from 41 1/2 to 48 1/2, the water from 5 to 6, the ash from 6 1/2 to 10, and the specific gravity from 1.316 to 1.341. In elementary analysis of a specimen from Cultivation Creek, we have:

| | |
|---|---|
| Carbon.................... | 68.018 |
| Hydrogen.................. | 6.480 |
| Oxygen.................... | 17.858 |
| Nitrogen.................. | .855 |
| Sulfur.................... | .189 |
| Ashes..................... | 6.600 |
| | 100.000 " |

Dr. Jackson was a pioneer geologist in New England, having made the first state surveys for Maine, New Hampshire, and Rhode Island, all in the 1830's and early 1840's. Dr. John Evans, who sent the coal samples to Dr. Jackson, was geologist on the U.S. Chiriquí Exploring Expedition of 1860. Although Jackson said that the speciments of coal collected by Evans came from the Gulf of Chiriquí (which is on the Pacific coast), it is certain that they came from the Lagoon of Chiriquí on the Caribbean side of the Isthmus. A belt of Tertiary rocks, which is known to be coal bearing, crops out there. The belt extends westward along the coast into Costa Rica, where the coal deposits described in this report are situated. Evans was at work on a final report of his geologic findings, including more complete descriptions of the coal occurrences, when he died.

In 1913, in Coal Resources of the World (v. 1, p. lxviii), the presence of coal in Costa Rica was reported by F. N. Cox as follows: "Samples of coal of good quality have from time to time been brought to San José from various parts of the country, but--upon examination the seams have proved to be of no economic value."

In volume 2 of the same work, a little additional information is given on the coal occurrence in Panama mentioned in 1860 by Dr. Jackson, including the fact that "one seam, from 7 to 9 feet thick (has been) noted."

In many places in Central America, there are additional reports of beds of coal. For example, in Guatemala in 1961 in the files of the Direccion de Mineria e Hidrocarburos, Miller found records of samples of coal from 58 different localities that had been submitted to the bureau for analysis.

Bohnenberger and Dengo (1978) describe the situation in Central America with respect to coal occurrences very accurately in the following paragraph.

"The information available reveals that emphasis has been placed on proximate analysis of coal samples by some government agencies, although the sampling techniques themselves are never stated. Descriptions of the locations of the coal or lignite outcrops generally are imprecise. Almost nothing is presented in the available reports concerning related geologic factors such as thickness of overburden, extent of the deposit, type and rank of the coal, average thickness of the coal beds, structure of the coal-bearing beds, water-gas content, and amount of coal dust. As a demonstration of the paucity of information, all that was available is presented in tables 1 through 9 for coals and lignites of each age group in Central America."

In Costa Rica, we are now aware of nine different localities where coal has been observed. These are shown in figure 3. They are reviewed in a later

--tion of this report. Mention has been made of several of these in reports that discuss energy resources. Bohnenberger and Dengo (1978) list six of the nine localities in their review, and show the available information in tabular form (table 1).

Bohnenberger and Dengo (1978) add "Our tabulations of coal or lignite proximate analyses were drawn from many different sources, some of which are not indicated specifically, and include private and governmental laboratories in Central America, as well as private and government research facilities abroad. The results reflect the sample as received by the laboratory. No one knows how the sampling was performed, how much the sample was dried, and how much time elapsed between the sampling and the analysis. Miller (1961) wrote: 'In order to have absolute or comparative value, a coal sample must be taken in a rigidly prescribed, meticulous manner, and must be hermetically sealed to prevent loss of moisture between the time of sampling and the time of analysis. It is extremely unlikely that the analyzed samples were taken in this manner, and hence the original moisture content of the coal is probably not correct.'"

## Recent investigations by ICE

Table 1 includes most if not all the information known about Costa Rica's coal beds up to 1978. At that time, however, ICE started a program of investigation of the coal potential of Costa Rica as a possible energy supplement to hydroelecticity. The area of particular interest was in southeastern Costa Rica, where petroleum investigations had gone on for years, and where coal deposits had long been reported. One of these coal occurrences in Limón Province is listed in table 1 as the Catarata (Cataract) 12 km west of Puerto Viejo. In this region coal outcrops are scattered over a wide area, and in some outcrops the coal beds appeared to be of significant thickness. ICE decided

Table 1.--Cenozoic "Lignite" beds of Costa Rica.* (in percent except as noted)

| Province | Name of prospect | Moisture | Volatile matter | Fixed carbon | Ash | Sulfur | Calorific value (Btu/lb) |
|---|---|---|---|---|---|---|---|
| Alajuela | Mid-course of Rio San Carlos | No additional information | | | | | |
| Alajuela | Region of El Venado, on north flank of Cordillera de Guanacaste, about 20 km northeast of Arenal Lake: Marcos Castro, no. 5 | 17.73 | 25.28 | 20.10 | 36.89 | 4.16 | 5,950 |
| | Rio La Muerte, no. 7 | 9.58 | 13.53 | 14.35 | 62.54 | 1.33 | 4,015 |
| | Quebrada de Trevino, no. 9 | 24.33 | 23.56 | 20.39 | 31.72 | 2.14 | 6,740 |
| | Danto, no. 2 | 22.92 | 22.72 | 12.89 | 41.46 | 2.69 | 4,578 |
| | Danto, no. 10 | 26.38 | 21.93 | 11.47 | 40.22 | 1.68 | 4,458 |
| | Raquel, no. 1 | 21.05 | 26.29 | 21.12 | 31.54 | 5.12 | 6,532 |
| | Bed no. 13 | 19.66 | 15.64 | 12.63 | 52.07 | 2.26 | 3,606 |
| | Bed no. 4 | 20.75 | 16.52 | 13.38 | 49.35 | 1.08 | 4,230 |
| | Rafael Mora, no. 11 | 28.22 | 36.82 | 14.07 | 20.89 | 1.22 | 7,257 |
| | Marcos Vargas, no. 2 | 28.07 | 26.40 | 19.98 | 25.55 | 1.25 | 6,729 |
| | Quebrada de Burio, no. 10 | 18.07 | 18.16 | 5.36 | 58.41 | 1.81 | — |
| Alejuela | Burio, no. 8 | 20.82 | 15.87 | 2.08 | 61.23 | 0.22 | — |
| | El Tunel, no. 1, bed no. 6 | 9.77 | 9.42 | 6.99 | 73.83 | 0.93 | — |
| Limón | Zent, 32 km southeast of Puerto Limon: Zent 1 | 31.55 | 39.39 | 19.73 | 9.33 | 8.93** | 8,730 |
| | Zent 2 | 30.25 | 47.22 | 16.64 | 5.89 | 0.61 | 10,257 |
| | Zent 3 | 23.87 | 48.29 | 24.13 | 3.71 | 0.42 | 10,700 |
| | Zent 4 | 24.43 | 45.34 | 26.20 | 4.03 | 1.09 | 10,350 |
| | Zent 5 | 23.85 | 42.48 | 20.09 | 15.58 | 3.90 | 8,830 |
| | Zent 6 | 24.15 | 42.48 | 25.28 | 8.09 | 2.36 | 10,889 |
| | Zent 7 | 28.38 | 42.47 | 21.13 | 8.02 | 4.74 | 10,215 |
| Limón | Catarata de Puerto Viejo, 12 km west of Puerto Viejo | Lenticular lignite beds, about 0.60 m thick, in siltstone-sandstone sequence of Gatun Formation (Miocene) | | | | | |
| San Jose | El Tablazo Hills, 2 km south of El Higuito | Lenticular lignite beds as much as 0.80 m thick, in siliceous sandstone; poor quality (Umana, 1964) | | | | | |

Note: Laboratory analysis by S. Bravo Perez, 1965, San José, Costa Rica.
*Quotation marks ("Lignite") are by Landis and Miller.
**Probably typographical error. Should be 0.93.

therefore to initiate a program of investigations to determine the quantity and quality of the coal.

The heart of the coal-bearing area, hereinafter called the Volio area, is the drainage basin of the Rio Carbon de Volio. This river flows south into the Sixaola River, which forms the boundary between Costa Rica and Panama. The area where the coal is found, north of the town of Volio, is an intricately dissected upland region of almost continuous jungle, except for several now unused small clearings for helicopter pads and one clearing on a ridge crest for pasture for cattle. Valley walls of the quebradas (small streams) in the drainage basin are steep, making climbing up or down difficult. The quebradas at stream level are quite narrow at their junctions with the main river, and get narrower and narrower headward. Outcrops of bedrock are numerous at stream level in the banks of the streams and in small cascades, small waterfalls, and several high waterfalls. Relief in most parts of the Rio Carbon drainage is less than 200 m. This rugged upland is bordered by a south-facing escarpment at the base of which lie the towns of Volio and Bribrí. To the south is an area of low hills, undoubtedly underlain by softer rocks than the upland. No detailed geologic mapping has been published or made public as yet to establish the precise relations between topographic features and geologic formations of the area. Much remains to be learned about the geology of the region--in fact almost everything.

When ICE decided to explore the potential for coal in the Volio area, it was realized that nothing could effectively be accomplished without a network of accurately located stations and accurate elevations to serve as a base map on which to plot data. Therefore mapping parties under the leadership of Hugo Taylor ran a series of north-south and east-west traverses with plane-table surveys. In addition, every quebrada in the area of interest was traversed at stream level. The details of this excessively arduous surveying comprise a network that was and still is of paramount importance for studying and accurately recording on a planimetric base the observed coal outcrops, and indeed all the bedrock geology of the area. A topographic map of the Rio Carbon drainage basin was also constructed, but the planimetry and topography were not fitted together.

In the course of the plane-table traverses of all the stream courses of Rio Carbon and its tributaries, and of other drainages of lesser interest to the north, east, and west, all coal exposures along the stream courses were accurately located, and wherever possible the thickness of the coal beds, and structural attitudes (dip and strike) were measured. All these data were recorded on the planimetric maps.

At numerous coal exposures, where enough of the coal bed was exposed or could be excavated without excessive work, samples were taken. Because coal beds sampled at the outcrop may be weathered and hence not reliable as to the coal composition underground, the composition of the coal samples as analyzed in the laboratory may not represent exactly what the unweathered coal will be like; neither is it known if the samples were hermetically sealed to prevent oxidation and loss of moisture between sampling and analysis.

In addition to the planimetric mapping, geophysical surveys were run to contribute to an understanding of the regional geology. These consisted of lines of gravity stations along highways and major drainages in a large area from Limón to the Panamanian border, and closely spaced lines of stations up major and tributary drainages in the region of coal interest. At some stations electrical resistivity measurements were also made.

The above described work consumed the better part of 2 years. At that time ICE decided to review the results to date, and to determine what the next stage of exploration should be. A summary report was prepared (ICE, 1980). The U.S. Geological Survey (through the Agency for International Development) was asked to study and analyze the results of work so far accomplished and to recommend what steps should be taken next in continuing the exploration.

## RESULTS OF PRESENT STUDY OF THE VOLIO AREA

The authors visited exposures of coal and associated rocks in the drainage basin of the Rio Carbon de Volio during a period of three days, May 4-6, 1981. The ICE personnel who accompanied the authors included some who had been involved in recent work in the area. In addition to the period spent in the southern Limón Basin, the authors spent several days before and after the field visit conferring with universally helpful ICE personnel in San José, and perusing reports and maps that were supplied by ICE. The following discussion is based on the information obtained both in printed and verbal form from ICE personnel and others in Costa Rica, plus the limited amount of data available from United States and international sources.

### Biostratigraphy

At the time of the authors' visit, major earth-moving activities were underway on part of the road between Puerto Viejo and Bribrí. The resulting fresh rock exposures were examined about 4 km northeast of Bribrí (near the junction of the Rio Sand Box and Quebrada Dos Aquas), and fossils were collected. An additional fossil collection was obtained from a loose boulder in the streambed of the Rio Carbon de Volio about 1.6 km north of Volio. In both of the collection areas, the fossil-bearing rocks were believed to be somewhere in the Gatun Formation. The fossils were examined by L. W. Ward of the U.S. Geological Survey. Ward's report on the collected mollusks follows:

"All L7 collections are from roadcuts northeast of Bribri, Costa Rica.

L7B - 20-50 feet above the lip of waterfall

Oliva sp. (Juvenile), possibly O. Brevispira Gabb
Antillophos mexicanus (Bose)
Sconsia laevigata sublaevigata (Guppy)
Distorsio sp. (juvenile)
Natica stenopa Woodring
Acteon sp.
Hannotoma sp.
Polinices sp. (several juveniles)

L7B - bag 3 or more
Polinices sp. (juvenile)
fragment of large gastropod

L7B - bag 2
bag apparently meant for microfossils
silty, very fine sandstone with carbonaceous material, very small mollusk fragments; fragments of echinoids

Cadulus sp. poss. C. Dentalinus (Guppy)

L7C [-2] near top of roadcut
strat below 7B and 7A

Melongena melongena consors (Sowerby)

Crepidula sp.
Dentalium sp.
2 lith - probably a burrowed contact
light-colored material contained Melongena
dark-colored (phosphatic) sediment contained Crepidula and Dentalium; dark-colored material probably occurs as burrows down into underlying light-colored sediment

L7C - near top of roadcut

Antillophos mexicanus (Bose)
Strioterebrum monidum (Woodring)
Mytilus sp.
Calliostoma sp.
Malea camura Guppy
Crassispira sp.
Agladrillia characta Woodring
Natica stenopa Woodring

L7C [-1]

*Natica stenopa* Woodring
*Concus* sp.
*Sconsia* sp.

L13 - From 1.6 km north of Volio

*Polinices* sp.
*Marginella* sp. 2 spec.
*Oliva* sp.
*Prunum gatunense* (Brown and Pilsbry)
*Dosinia* sp. (Young)

Summary: As you probably know, Woodring was the last U.S. Geological Survey paleontologist with expertise in this area of the world. Using his and A. A. Olsson's (1922) works on Central America it was concluded that the majority of material indicated upper Gatun Fm. This meant late Miocene to early workers, but more recently beds which correlate with the upper Gatun have been assigned to the Lower Pliocene.

Taxa indicate shallow-shelf, open-marine, sub-tropical conditions. However, these are faunal components that appear more temperate and may indicate an area of upwelling of cooler currents.

Collections over a wide area, with an eye to superposition, contacts, mixing of faunas, etc. are necessary to further refine biostratigraphic data."

## Coal beds

Part of the recent work of ICE in the Rio Carbon de Volio area consisted of traversing the Rio Carbon and the quebradas tributary to it, locating the outcrops of coal beds and associated rocks, determining the attitude of the coals and associated beds, and collecting samples of the coals for chemical analysis. No attempt was made to determine the stratigraphic relationship of the coals and associated rocks and map the coal beds or other stratigraphic entities, nor to derive related information about thickness of overburden and persistence of the coal beds. Consequently much remains to be learned before the resource potential and recovery possibilities can be evaluated. However, some data of value about the coals can be derived and summarized from the pre-existing information, and from data and samples collected during the field visit.

Occurrence.--The coals exposed in the Rio Carbon de Volio area are in the Gatun Formation of Miocene and possibly lower Pliocene age. However, the exact placement of the coal-bearing rock sequence within the Gatun is unknown. Bohnenberger and Dengo (1978, p. 69) felt that all carbonaceous beds of Cenozoic Age were in the upper part of the Gatun Formation. A generalized geologic map of the Volio area (fig. 10) supplied by ICE, which covers the Rio Carbon de Volio drainage basin, indicates a subdivision of the Gatun into three parts, and the coals exposed in the Rio Carbon would be present in the two lower parts of the Gatun as mapped in the area. To complicate the problem still more, the contact of the Gatun with the underlying Uscari Formation is shown as a fault of unknown displacement.

The number of individual coal beds or coal zones present in the Rio Carbon de Volio area remains to be determined. The limited field visit did indicate that individual coal beds extended for distances of as much as 500 m and that at least three and perhaps as many as five or more individual coal beds are present in the area.

The type of map information now available for most of the Rio Carbon de Volio drainage basin is illustrated in figure 11. The map covers the southern part of the basin. It is a composite of two separate maps prepared by ICE, the first showing by contours at 10-meter intervals the topography of the area. On this map we have superimposed data from a planimetric map of the same area showing the location of coal outcrops, and the attitude of the coal beds. The original (ICE) planimetric map also included figures giving the thickness of each coal bed, where the mapping team was able to make accurate measurements. These measurements have not been included in figure 11.

These data are extremely useful, and will save any follow-up team of geologists a great deal of time. The data do not, however, resolve the fundamental questions of how many coal beds there are, what is their stratigraphic relation to each other, and what major and minor structures affect the coal-bearing sequence of beds.

A test case, and probably the easiest one, involves the coal exposures along a tributary of the Rio Carbon in the southwest part of the map (fig. 11, drainage marked M-5 and M-43). From a study of the map it is not possible to tell how many coal beds are present along this valley floor. The authors traversed the valley, and found that all coal outcrops are on one and only one continuous bed.

Thickness.--Coal beds were measured by ICE (1980) at 94 outcrops in the area. Seventy percent of the beds measured were between 0.25 m and 1 m thick, 14 percent were less than 0.25 m, and 16 percent exceeded 1 m. The thickest bed measured was 2.2 m but no other measurement exceeded 1.5 m. The average of the 94 measurements is 0.63 m. The significance of these numbers is difficult to evaluate, considering the lack of stratigraphic understanding of the area. However, one coal bed that was traced during the field visit had been measured at seven locations in a distance of 370 m. The greatest was 1 m and the smallest 0.76 m.

Attitude.--Strike and dip measurements of coal beds and associated strata were taken at 107 points by ICE (1980) in the Rio Carbon de Volio area. The arithmetic mean (average) of the dip measurements is 19°; 34 percent of the dip measurements are from 16° to 20° and 20 percent are from 11° to 15°. Because 89 percent of the dips fall between 6° to 30°, it follows that in few places are the dips nearly flat or overly steep. Most of the dips are to the north and a large majority of the measured strikes are within 30° north or south of due east.

Quality.--The determination of coal quality is vitally important from all aspects of mining, treatment, transportation and use. Characterization of the quality of coals is completely dependent on every facet of a process that begins with the necessary decision about selection and size of samples, methods of collection and handling of the samples, and analytical practices and methods. The end results of the process must be sets of data that possess both accuracy and precision; that is, the data must be correct and must be internally and externally reproducible and comparable. Lack of care or use of improper methods and procedures at any point in the sampling and analytical process invalidates the results. Suggestions about description of coals, sampling, sample handling, etc., are included in such sources as Schopf (1960), Dutcher (1978), Swanson and Huffman (1976), Averitt (1975), and Hobbs (1979). Standard procedures for analyzing coal are presented in the current book of American Society for Testing and Materials (1980) (ASTM) standards, Part 26, and the place and functions of the laboratory, and uses and limitations of coal analyses, are discussed by Berchtold (1981) and Rees (1966).

Rank.--Coal can be classified in several ways, but the classification by rank--that is, by degree of metamorphism in the progressive series which begins with peat and ends with graphite (Schopf, 1966)--is the most commonly used system. The position of a coal within the metamorphic series is dependent upon the temperature and pressure to which the coal has been subjected and the duration of time of subjection.

Various schemes for classifying coals by rank have been proposed and used, but the most commonly employed is the "Standard specification for classification of coals by rank", adopted by the ASTM (1980). The ASTM classification system differentiates coals into classes and groups on the basis of mineral-matter-free fixed carbon, or volatile matter, and the moist mineral-matter-free heating value supplemented in some cases by determination of agglomerating (caking) characteristics. Figure 12 compares in histogram form the heating values and moisture, volatile matter, and fixed carbon contents of coals of different ranks. As pointed out by the ASTM (1980), a standard rank determination cannot be made unless the samples were obtained in accordance with standardized sampling procedures. However, nonstandard samples may be used for comparative purposes through determinations designated as "apparent rank."

Sixty-nine samples, 67 from outcrops and 2 from drill holes, were collected and analyzed during the recent ICE (1980) work in the southern Limón Basin. Sampling methods, procedures, and handling are not known to the authors. Presumably, the analyses were done in the laboratories of ICE.

Two samples collected during the authors' visit were analyzed by Commercial Testing and Engineering Company laboratory in Denver, Colorado. Both samples came from outcrops previously sampled and analyzed by ICE.

Table 2 presents the analytical results on sample L-5, a chip-channel sample representing 1.07 m of coal, which partly duplicates sample M-53 of ICE (1980) that represented 1.4 m of coal at the same outcrop; and sample L-8, a grab sample about 0.15 m thick near the middle of a 0.8 m thick coal sampled as M-5 of ICE (1980). The L samples were packed in double and triple layers of plastic bags as soon as possible after collection and were analyzed about one month after collection. Both samples indicate an apparent rank of subbituminous C (table 2). In contrast, both samples M-53 and M-5 of ICE indicated to them an apparent rank of high volatile C bituminous. The reasons for these differences are not apparent with the information available.

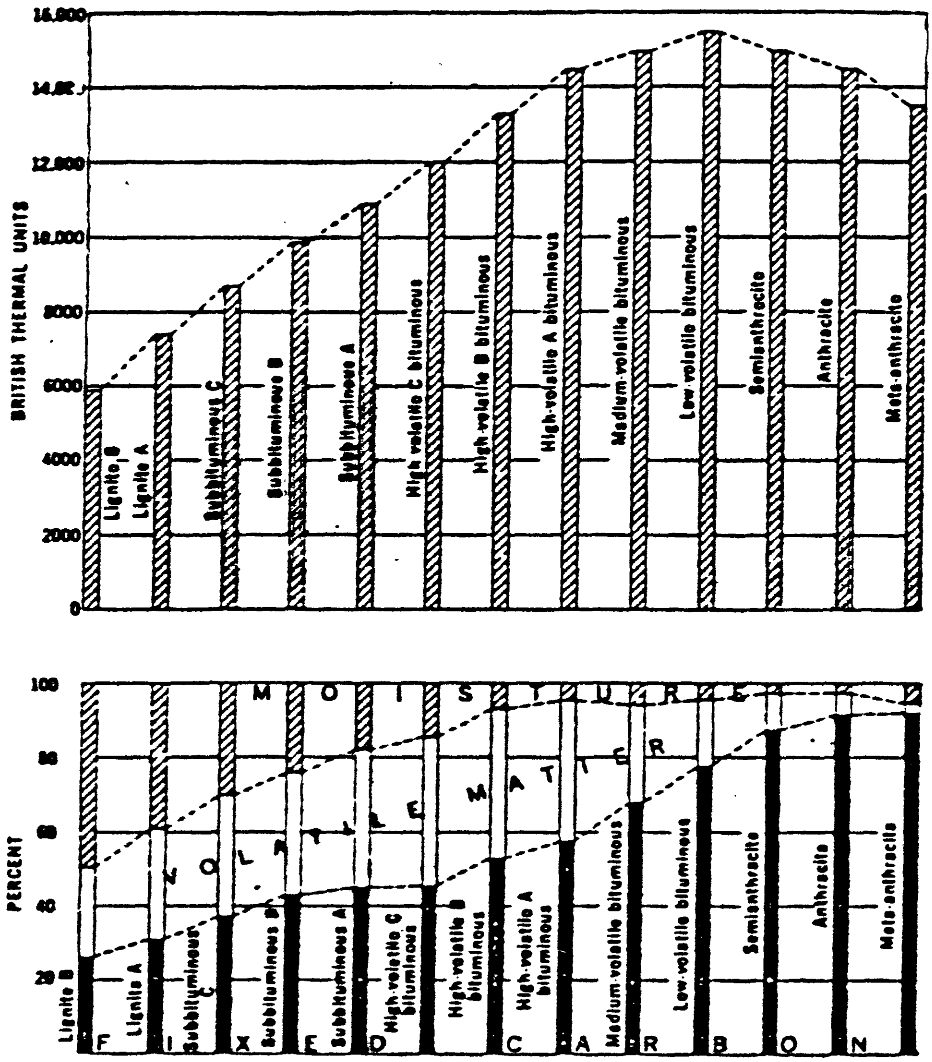


Figure 12. Comparison on moist, mineral-matter-free basis of heat values and proximate analyses of coals of different ranks.

Table 2 .--Analyses of Costa Rican coal samples

(Analyses of L samples by Commercial Testing and Engineering Co., Denver, CO.)

| | Moisture | Volatile matter | Fixed carbon | Ash | Hydrogen | Carbon | Nitrogen | Oxygen | Sulfur | Heat Value (Btu) | Apparent rank | Other |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| L-5-1.07 m thick | 26.67 | 36.03 | 29.16 | 8.14 | 3.85 | 47.66 | 0.85 | 11.94 | 0.89 | 8,275 | SubC | Hardgrove Grindability Index 41.4 at 22.4% Moisture Equilibrium Moisture 26% Apparent Specific Gravity at 26.67% Moisture 1.30 Chlorine 0.00% |
| | --- | 49.13 | 39.77 | 11.10 | 5.25 | 65.00 | 1.16 | 16.27 | 1.22 | 11,285 | | |
| L-8-0.15 m thick | 25.00 | 36.87 | 30.30 | 7.83 | 3.65 | 48.34 | 1.07 | 10.90 | 3.21 | 8,558 | SubC | Hardgrove Grindability Index 40.4 at 23.91% moisture Equilibrium Moisture 25.2% Apparent Specific Gravity at 25% Moisture 1.30 Chlorine 0.00% |
| | --- | 49.16 | 40.40 | 10.44 | 4.86 | 64.45 | 1.43 | 14.54 | 4.28 | 11,410 | | |

Grade.--Classification of coal by grade is based largely on the percent content of ash, sulfur, and other constituents that adversely affect utilization. As shown in table 2, the two samples collected by the authors contain 0.55 percent and 3.21 percent sulfur and 8.14 percent and 7.83 percent ash. The 69 samples collected and analyzed by ICE (1980) had an average sulfur content of 2.34 percent and average ash content of 14.22. Thirty five percent of the samples were in the low sulfur content (1.0 percent or less) class, and 36 percent were in the medium sulfur content (1.1 percent through 3.0 percent) class. Fifty eight percent of the samples had 10 percent or less ash content, 23 percent had 11 through 20 percent ash content, and 19 percent had 21 percent or more ash.

From environmental standpoints, sulfur is considered to be the most deleterious constituent of coals. Sulfur occurs in coals in three forms, organic, sulfate, and inorganic (primarily the minerals pyrite or marcasite). The sulfate form is almost always very low or nonexistent in freshly mined coal, the organic form commonly includes the bulk of the sulfur in low-sulfur coals and a much lesser percentage of the sulfur in high-sulfur coals, and the inorganic--sometimes called pyritic sulfur--ordinarily makes up the bulk of the sulfur in high-sulfur coals.

Ideally, coals of less than 1 percent sulfur should be used for most, or all, purposes. However, in actual practice, some coal containing as much as several percent sulfur is used in some areas. Use of higher sulfur coal is often accompanied by treatment of smokestack emissions to control the amount of sulfur dioxide released to the atmosphere. Megascopic examination of the coals of the Rio Carbon de Volio area in the field shows that pyrite occurs as scattered, infrequent lentils as much as 1 mm thick and several centimeters long. Perhaps the high-sulfur sample (L-8) collected by the authors contained one or more of these lentils.

No definitive conclusions about sulfur content of the coals in the area can be made without further careful sampling, megascopic and microscopic description, and analyses to determine the forms of sulfur present in the coals. Probably most of the coal beds in the area contain less than 10 percent ash when sampled so as to exclude obvious non-coal material. Most coals utilized in the world contain less than 10 percent ash. Coals with more ash can be, and are, used under special circumstances.

Petrography.--Megascopically, the coal is nonbanded, dull and tough, and has conchoidal fracture and very little development of systems of vertical joints known as cleat.

The coal was examined microscopically by N. H. Bostick and C. S. Heustis of the U.S. Geological Survey. According to Bostick (written commun., 1981):

1) The sample is mainly comminuted plant fragments with good planar structure but little concentration of different constituents into layers. The preparation was crushed to rice size, and it contains several grains of fairly homogeneous vitrinite that could have been layers large enough to see megascopically.
2) Mineral matter is low, less than 10 percent, probably less than 5 percent. Thus the coal is not attrital in the sense of the widespread stream-influenced Gondwana coals but is really clean attritus as the term was used by early North American petrologists.
3) Pyrite is scattered large broken framboids (clusters of tiny pyrite cubes or grains) or small framboids in the few vitrinite grains. The total is low. I would guess typical of a coal with about 1 to 1-1/2 percent sulfur.

4) The vitrinite reflectance is .25 percent to .30 percent Ro--below defined levels of rank but a level usual for subbituminous C. Polish quality and lack of desiccation or surface "heaving" suggest that the sample would not be a lignite but could be subbituminous B or possibly A. At this rank the "vitrinite" would be correctly termed preserved woody tissues.

5) Liptinite is unusually abundant, consisting of resin balls, leaf cuticle, pollen grains and a few algal bodies plus the fine broken debris of all these. The total liptinite is at least 10 percent, but I estimate that with the fine debris the total is 20-30 percent of the sample. Since the larger algal bodies are rare, perhaps the fine debris is not algal, but there is no way to know.

6) Fungal spores, sclerotia, are common.

7) Exudatinite--a secondary flourescing material in voids of sclerotia and fusinite--is common.

8) "oil" blooms--bursts of orange-fluorescing oil possibly like petroleum--are occasional. But they are different from those I have seen in petroleum-bearing coals in that they come only from the edge of grains, not from cracks or voids, and they contain "dust" grains within the oil. If one had a coal that had been contaminated by a small amount of oil or diesel fuel or an oil-bearing drilling fluid I would expect to see something like this.

9) There is no sign of weathering.

## OTHER COAL LOCALITIES

Eight other coal-bearing localities besides the Volio area are known to the writers. Five of these were included by Bohnenberger and Dengo (1978) in their table of lignite beds of Costa Rica (table 1). Some data on general location and a few analyses of samples are shown in the table, but practically no information about the other localities seems to be available. For those coal samples that were analyzed, there may be additional information about the coal beds in Costa Rican government files, but if so, we have not found the correct sources.

### El Venado

Multiple outcrops of coal are known near the town of El Venado in Alajuela Province. This is a region of dense jungle on the north flank of the Cordillera de Guanacaste, about 20 km northeast of Arenal Lake (fig. 3). Eleven samples of coal were collected and analyzed from this area many years ago, but how many coal beds are present, how thick they are, and other most important information about them seems not to be available.

Most of the samples showed ash content of more than 30 percent, and low calorific value of less than 6000 Btu/lb. Two of the samples were of somewhat better quality coal, and if sufficiently thick, could be of economic interest. We do not know how the samples were taken, or what type of contamination may be responsible for the high ash content. Pending more definitive data, the El Venado coal should not be condemned on the basis of 11 analyses of undescribed samples.

R. L. Miller and Frank Spencer of the U.S. Geological Survey visited the El Venado area in 1966 and during the course of a one-day excursion, were able to visit several of the lignite exposures. At one locality, two lignite(?) beds crop out about 14 m (46 feet) apart stratigraphically. The lower, about 2.8 m (9.2 ft) thick is contaminated with clay and therefore would have a high ash content. The upper bed is of better quality; where augered it was said to have been 1.25 m (4.1 ft) thick. The beds at this locality dip 16°, which would severely limit the tonnage that could be successfully strip mined because of excessive thickness of overburden in a relatively short distance horizontally. Unfortunately, the name given to Miller for this locality by a local guide does not match any of the names in the table of analyses (table 1), so the composition of these beds is not known. At another location a lignite bed known as Danto 2 is 0.3 m (1 ft) thick and dips at an angle of 29°, and in the same area, bed Danto 10 is 2.7 m thick and dips at 60°. These two beds are the ones shown in table 2, in which the ash content is over 40 percent. Samples from two other lignite beds in the Venado area, named Rafael Mora and Marcos Vargas, have the lowest ash and highest heating value of any (table 1), but information on their location, thickness, and attitude of these beds is not available.

The Venado coal-bearing area is remote from centers of population and industry, but hardly more so than the Volio area. Access is difficult, but may be better than indicated by roads shown on small-scale maps. Topography is considerably gentler than in the Volio area. Some of the coal beds are significantly thick, and may be of good quality.

A more thorough investigation of the Venado area seems desirable concurrent with geologic studies of the Volio area.

## Zent

Coal beds are known to be present southwest of the town of Zent, 27 km west of Limón (fig. 3). The writers do not know whether all the coal outcrops are along the Rio Zent, which is in the Province of Limón, or whether some may be located along the Chirripó River, which forms the border between Limón and

Cartago Provinces. Here also the coals have been sampled, and seven samples have been analyzed (table 1).* No descriptions of the beds from which the samples were collected are known, nor have we found descriptions of the specific locations of the beds. The analyses show coal of good quality, all but one sample containing less than 10 percent ash, and all but two yielding more than 10,000 Btu/lb.

The town of Zent is accessible on an all weather road, near the main highway from Siquerres to Limón. How far up river from Zent and in what topographic and geologic environment the coal beds occur is unknown. Based on the apparent good quality of the samples, the area merits a careful look by coal geologists.

## El Tablazo Hills

"Lignite" bed(s) have been reported in the El Tablazo Hills 10 km southeast of San José, and about an equal distance west of Cartago (fig. 3). No map showing the exact location of the coal outcrops has been found, but the coal beds seem to be in the Coris Formation of early Miocene(?) age. The Coris is about 60 m thick in this area and consists of yellowish-gray to reddish-orange argillaceous sandstone, but it does include lenses of lignite (Krushensky, Malavassi, and Castillo, 1976, and oral commun., 1981).

The structure in this region is dominated by subparallel anticlines and synclines trending east-southeast. The position of the lignite beds with respect to these folds is unknown. Apparently no geologist has described this coal occurrence comprehensively, but Jorge Umana reports (table 1) that "lenticular lignite beds as much as 0.80 m thick are present" and are of "poor quality."

* In table 1, the location of the Zent area is erroneously given as southeast of Puerto Limon. It is west of Puerto Limon.

The consensus is that the "lignite" beds are too thin or too low grade or both to merit much attention. Nevertheless, the lignite is so easily accessible and so close to centers of population and industry that several days of field work and sampling would be worthwhile, in the interests of describing and publishing the pertinent geologic data on these coal beds. Coal beds no thicker or higher grade than at El Tablazo Hills are being exploited elsewhere in the world on a small scale for local use, such as space heating, cooking, and other small consumption activities.

## Rio San Carlos

The approximate location of this coal, which is in the province of Alajuela, is shown in figure 3. It has been described as being in the middle course of Rio San Carlos. It is probably near the junction of Rio San Carlos and Rio Tres Amigos. We know almost nothing about it, but we assume that it is in a region of extensive jungle and that access may be difficult. ICE (1980) reports one sample from this locality, the analysis of which showed 11.4 percent ash and 0.45 percent sulfur. Calorific value of the sample was 6167 KCal/kg (11,100 BTU/lb). Other elements of a proximate coal analysis are not given, but the coal was classified as bituminous by the analyst.

Possibly this coal occurrence is so remote from the heartland of Costa Rica and so difficult of access that it could not be developed even if all other factors were favorable. Nevertheless the one sample appears to be of a quality meriting a little more attention.

## Upala

Still another coal occurrence identified as lignite is in Alejuela Province (fig. 3). The exposures are probably on Rio Zapote near the town of Upala. This town is about 8 km south-southwest of the Nicaraguan border and 20 km south of the south shore of Lake Nicaragua. Only one sample from this "lignite" has been collected and analyzed. It contained 60 percent ash and had a heating value of only 3998 Kcal/kg (7196 BTU/lb.). We have no additional information, but it would be presumptuous to condemn a mineral prospect on the basis of only one sample and no other information. Possibly the Upala "coal" deserves another look. Access to this area would not seem to be difficult.

### Esparta

Another little-known coal locality is in Puntarenas Province. It apparently is near the town of Barranca, probably on the river of the same name. Only one sample from this coal has been analyzed. It showed 63 percent ash and heating value of 4615 KCal/kg (8307 BTU/lb). The coal was classified as subbituminous, though the basis for this ranking is not apparent. If the one sample is indeed representative of the coal bed from which it was taken, the very high ash content would render the coal uneconomic regardless of any other factors. The questions remain, however, as to whether the sample was representative, and is there only one coal bed?

There appear to be good roads into this area.

### Puriscal

A second prospect in San José Province has been named the Puriscal occurrence. It has been difficult to locate this prospect, even approximately. It may be on or near the Rio Siguiarea or Rio Segundo south of the city of Alajuela, and approximately 20 km west of San José.

The coal bed(s) have not been described or sampled. Access to the area (wherever it is) should be easy.

### Siquirres

A final coal prospect is near the town of Siquirres, on Rio Pacuare, probably in the eastern of the two areas of Oliogocene-Miocene rocks shown on the geologic map of Costa Rica (Dondoli and others, 1968) a few km south of the town. This coal was called to our attention by Hugo Taylor (oral commun., 1981). We have been unable to find out anything else about the occurrence, but it may deserve location, description, and sampling by a coal geologist.

## PROBLEMS

As pointed out previously, details of the stratigraphy and structure of the late Tertiary rock sequence in Costa Rica are poorly known. The exact stratigraphic position of coal-bearing and potentially coal-bearing rock sequences is practically unknown. In past investigations only small parts of needed coal resource information have been gathered, or recorded. With a few exceptions, the geology of areas that do or might contain coal has not been studied, or the available information is scanty.

### Stratigraphy

The relationship of Wards' suggestion that the fossils from the Volio area might represent the upper part of the Gatun Formation, the authors' impression that the fossiliferous rocks were stratigraphically close to the coal-bearing rock sequence, the statement by Bohnenberger and Dengo (1978) that "All reported localities (of carbonaceous beds) seem to be confined to the upper part of the Gatun Formation...", the map that seems to place the coal in the lower and middle parts of the formation, and the faulted(?) contact of the Gatun and Uscari Formations (fig. 10) cannot be evaluated with the information available.

### Structure

The Tertiary geologic history of Costa Rica is complicated because of folding and faulting that both accompanied and followed the deposition of the potential coal-bearing rock units of late Tertiary age. The structural deformation was usually related to or accompanied by intrusive and extrusive igneous activity, which further complicates the situation. In some areas where mapping and stratigraphic studies were done in support of oil and gas exploration, some structural interpretations have been made, but in much of the country there have been no such studies. The geologic structure of coal-bearing areas must, of course, be known before coal resource potential and recovery possibilities can be assessed.

### Coal beds

Knowledge of the stratigraphic position, number, correlation, and lateral persistence of the coals in a coal-bearing area is fundamental to determining the coal resource potential of the area. At present, these geologic facts are apparently not known in sufficient detail in any part of Costa Rica.

### Coal quality

In the past, all coals in Costa Rica were classed as lignite on the basis of little or no information. However, the available analyses indicate a considerable range in rank from lignite to bituminous coal. An understanding of the rank and grade of Costa Rica's coals is absolutely necessary before the various options for potential utilization can be evaluated.

### Resources

The coal resource potential of Costa Rica cannot be adequately assessed at this time. Even in such areas as the Rio Carbon de Volio, a valid coal resource estimate on a bed-by-bed basis is dependent on geologic mapping and correlation of the individual coal beds and associated rocks, accompanied by detailed stratigraphic and structural studies.

### Logistics

The transportation network of Costa Rica is minimal in many of the potentially coal-bearing parts of the country. Considerable amounts of foot travel can be expected during geologic field work, with the resulting penalties in time. Four-wheel-drive vehicles are desirable and sometimes necessary. Helicopters can be, and reportedly have been, used in the Rio Carbon de Volio area to supply tent camps, and might be usable in other areas for both supply and field work uses.

Housing, food facilities, and other support services may be primitive or nonexistent in many areas. For example, the ICE personnel reportedly operated from self-sufficient tent camps in parts of the southern Limón Basin. During their visit, the authors stayed in a poor hotel in the town of Cahuita and ate breakfast and supper in a local restaurant with good but limited menu. Another satisfactory restaurant is in Bribrí and another restaurant, untried, is located in Puerto Viejo. Small stores are present in Cahuita, Puerto Viejo, Bribri, Volio, and at several other locations, and all can usually supply the dietary staples of the area--rice and beans plus some canned goods and fresh vegetables and fruit.

The town of Limón has good hotels and restaurants, and is the best base of supplies in the Limón Basin. Unfortunately, it is not within practical four-wheel vehicle commuting distance of some of the potential work areas in the southernmost Limón Basin. However, Limón would be an excellent center for helicopter-supported operations over much of the Limón Basin.

Satisfactory local rental housing for office and personal use is reportedly difficult to obtain in most places. One housing alternative would be self-contained trailers such as the 24 to 28 footers commonly used for field work by the U.S. Geological Survey. Such trailers may not be available in Costa Rica, but could be introduced through the port of Limón and hauled over existing roads to points of use.

# RECOMMENDATIONS

The following set of recommendations for future work plans is in two parts. The first part applies to the Volio area. The second part applies to areas outside of the Volio area that are known to contain coal.

## Volio area

The Volio area is, to the authors knowledge, the only part of Costa Rica that has received any attention from the standpoint of coal resources. The outcrop areas along streams have been traversed and coal outcrops located on a planimetric base map, the thickness and attitude of the outcropping coal beds have been determined; coal samples have been collected and analyzed, a generalized geologic and structural map of the area has been prepared at a small scale, and topographic maps of parts of the area have been prepared. Therefore, in the Volio area, particularly in such parts of it as the drainage basin of the Rio Carbon de Volio, much of the preliminary work needed for a valid coal resource assessment has been completed.

The work still required is: 1) geologic mapping, stratigraphic section measuring, and paleontologic studies, with the intent of understanding the geology of the coal-bearing sequence. A primary objective is establishing the correlation of the outcropping coal beds and other laterally persistent strata so that an estimate of the coal resources may be made. Another important objective is the creation of a stratigraphic model that may be applicable to, and may aid in understanding, other known coal-bearing areas in Costa Rica. 2) Near the completion of, or following step 1, locations should be selected for about 10 exploratory drill holes. Four or more of the holes should be located so as to penetrate as much as possible of the Gatun Formation and provide data to help understand the stratigraphic framework of the Gatun in the area. These holes may be as deep as 1,000 m or more, should terminate in rocks of the Uscari Formation beneath the Gatun Formation, should be geophysically logged to produce a suite of logs that include self-potential, resistivity (focused resistivity, if possible), and some measure of bulk or formation density in grams per cubic centimeter. The rock cuttings produced during drilling should be sampled by a geologist at points representing every 2 m of depth. Provision should be made for obtaining core samples of coal and associated rocks through the twin-hole method (Hobbs, 1979). The remainder of the holes should be sited to obtain information about the thickness, persistence, and attitude of the coal beds and associated rocks to supplement and complement the data obtained through surface outcrop examination and mapping. In addition, each of these holes should yield core samples of coals and associated rocks so the quality of the coals may be determined and, if desirable, the engineering properties of the rocks associated with the coal beds may be measured. The holes should be located to obtain information about and samples from each of the coal beds that might be considered for mining. The twin-hole method should be standard for these holes, all of which would probably be less than 300 m deep. All the drilling proposed here would be planned and located to provide data necessary for stratigraphic understanding of the coal-bearing rock sequence and for a preliminary evaluation of the coal resource (<u>not</u> reserve or available tonnage) potential of the area.

At the conclusion of the drill program, all information should be gathered, synthesized, and evaluated to produce a report or reports on the results of the field and office investigations. Report elements that should be included in conjunction or separately are:

1. Geologic map and cross section at a scale such as 1 to 5,000.
2. Map showing the thickness and distribution of individual coal beds.

3. Map showing the thickness of overburden above potentially recoverable coal beds.
4. Map showing the areas in which resources of different categories are estimated to be present.
5. Tabulations of resource estimates in standard categories.
6. Tabulations of analytical data on coal quality.
7. Tabulations of point data such as measured stratigraphic sections and drill hole information (including geophysical logs and results of sample interpretation).
8. Such other derivative maps, charts, or tables as may be possible and desirable.
9. Text material describing the results of the investigation and recommendations stemming therefrom.

The geologic work required in the Volio area could best be done by a geologic team consisting of two geologists experienced in geologic mapping and related studies of coal-bearing and associated rock sequences, two counterpart geologists--perhaps selected by ICE--who would gain experience in the philosophy and methodology of coal resource assessment, and two or more experienced helpers to operate vehicles and provide other support as needed.

A capable, competent, smoothly functioning geologic team might, depending on weather, housing, amount and type of support, etc., complete the fieldwork in a period of 3 to 6 months--depending on the amount of drilling and the time-relationship of the drilling activities to the other field work. An equal or greater amount of time--again depending on the timing of drilling activities to produce samples and other information--would be required to study rock samples, integrate data on coal and other rock sample analyses, etc., and prepare the final reports.

A forecast of the time required from initiation of activities to completion of final reports is not now possible. Such timing is dependent on factors that are not definable at this time. These factors can only be precisely determined during the course of the field and office work--for example, number of drill holes, total footage, total core footage, time of drilling, number of rock and coal samples and fossil collections, time required to study same, and necessity for supplementary or complementary studies to resolve unanticipated problems.

Regardless of the time required, the intent of the detailed geologic study of the Volio area should be to provide a basic understanding of the coal geology in all its facets in a relatively small area in which the coal-bearing rocks are well exposed and where the necessary preliminary work--such as topographic studies and location if coal outcrops--has been completed. This basic geologic information can then be used to help unravel the coal geology of the southern Limón Basin by extrapolation, and by comparison with results of geologic studies of other known coal areas in the region.

## Other areas

Besides the Volio area, eight other localities in Costa Rica where coal beds are known have been very briefly described. Unfortunately, little additional information about them seems to be available, and the location of some of them is quite vague. It may be that the Volio area offers the best prospect for coal beds that might prove to be exploitable. At the present time, however, this is a supposition, not a known fact. One or more of these little-known coal localities could prove to be better prospects, when all factors are considered, than the Volio area.

Figure 13 shows the known outcrop areas of the Gatun Formation in Costa Rica, and the additional areas of younger rocks that may possibly be underlain by the Gatun. In these areas of younger rocks, the Gatun may be present at depth or it may 1) never have been deposited at any one point, 2) may have been removed by erosion preceding deposition of younger rocks, or 3) may not have been the site of coal-forming depositional processes. Nevertheless, the figure does indicate that a fairly large area in Costa Rica may have at least some potential for containing coal.

A team of two geologists, one U.S. and one Costa Rican, with supporting personnel, could in 3 or 4 months' time make preliminary field investigations at all eight prospects other than the Volio area, including sampling, and a limited amount of geologic mapping to determine how good (or poor) these prospects are. An additional 4 months of laboratory work and report preparation would probably be needed for these investigations. Only then will it be possible to say whether the Volio coal beds offer the best likelihood of being exploitable of any prospects in Costa Rica. In addition there should be a preliminary evaluation of each of the eight prospects, an important objective in itself.

A geologic study of these other lesser known coal beds could proceed simultaneously with the intensive geologic study of the Volio area, recommended above. Because of the heavy expense of exploratory drilling in remote areas, the supplemental study of the other areas should precede any large investment in physical exploration at Volio.

## CONCLUSIONS

Although coal has been known in many places in Central America, and as far back as 1860, no significant effort to evaluate the economic potential of any deposit has been made other than the current program of the Instituto

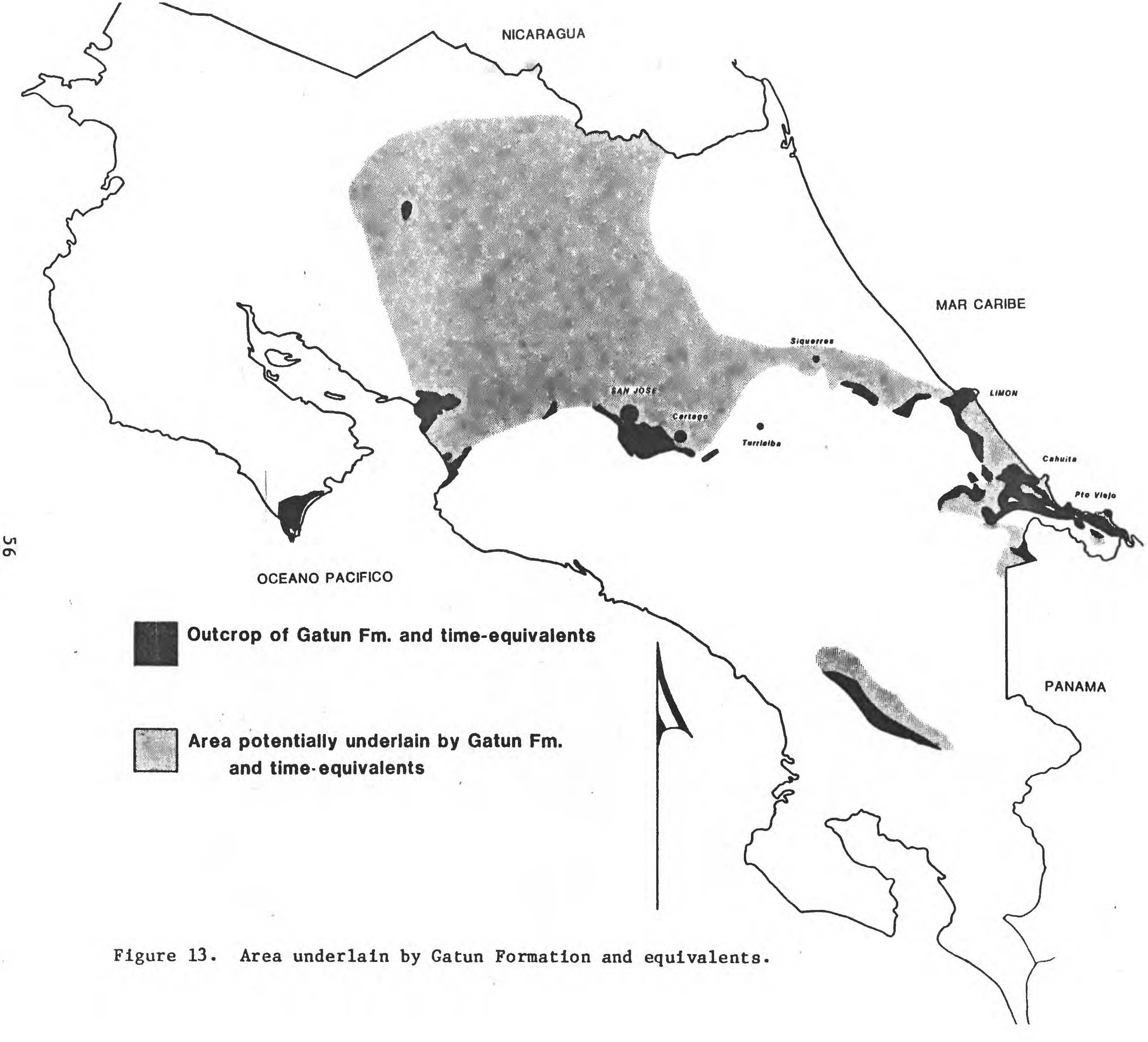


Figure 13. Area underlain by Gatun Formation and equivalents.

Costarricense de Electricidad in the Volio area. Hydroelectricity figures prominently in the energy budget of Costa Rica, and imported oil will continue to be a large item in that budget. However, possible contributions from other energy sources deserve consideration in Costa Rica, as in many other countries, in order to meet part of the demand for energy locally, if not nationally. As a source of additional energy for the country, coal seems to offer a prospect for success. It behooves the country to move forward with its program of investigating its coal resources, after the fine start that has been made. At this time there is reason to hope that coal will prove to be a usable source of energy in Costa Rica.

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