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Earth and Water Resources and Hazards in Central America

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By Charles G. Cunningham, Raymond W. Fary, Jr., Marianne Guffanti, Della Laura, Michael P. Lee, Charles D. Masters, Ralph L. Miller, Ferdinand Quinones, Roger W. Peebles, John A. Reinemund, and David P. Russ

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ABSTRACT

Long-range economic development in Central America will depend in large part on production of indigenous mineral, energy, and water resources and on mitigation of the disastrous effects of geologic and hydrologic hazards such as landslides, earthquakes, volcanic eruptions, and floods. The region has six world-class metal mines at present as well as additional evidence of widespread mineralization. Systematic investigations using modern mineral exploration techniques should reveal more mineral deposits suitable for development. Widespread evidence of lignite and geothermal resources suggests that intensive studies could identify producible energy sources in most Central American countries. Water supply and water quality vary greatly from country to country. Local problems of ground- and surface-water availability and of contamination create a need for systematic programs to provide better hydrologic data, capital improvements, and management.

Disastrous earthquakes have destroyed or severely damaged many cities in Central America. Volcanic eruptions, landslides, mudflows, and floods have devastated most of the Pacific side of Central America at one time or another. A regional approach to earthquake, volcano, and flood-risk analysis and monitoring, using modern technology and concepts, would provide the facilities and means for acquiring knowledge necessary to reduce future losses.

All Central American countries need to strengthen institutions and programs dealing with earth and water resources and natural hazards. Some of these needs may be satisfied through existing or pending projects and technical and economic assistance from U.S. or other sources. The need for a comprehensive study of the natural resources of Central America and the requirements for their development is evident. The U.S. Caribbean Basin Initiative offers both an excellent opportunity for a regional approach to these pervasive problems and an opportunity for international cooperation.

INTRODUCTION

BACKGROUND

Economic well-being in Central America (fig. 1) has been of growing concern to the United States. Because of this concern, President Reagan has announced plans for a Caribbean Basin Initiative, which will provide a new approach to the economic development of the region. The program, approved by Congress, provides for free-trade guarantees and incentives and technical assistance. Much of the economic assistance will provide funds for imports essential to maintaining production and employment. The U.S. Agency for International Development (USAID) is using the remainder to support 120 individual development projects.

This current U.S. commitment to the Central American region is directed toward long-term economic development and a permanent increase in productivity and employment. In order to achieve these results, individual Central American countries need to inventory available indigenous resources and make effective use of those that can be developed. These resources, including land, energy, minerals, water, and people, must be used wisely for the development of agriculture, industry, and trade. Not only will gross national products increase, but the burden of expensive imports will also be eased. In addition, means should be found to minimize the devastating effects of the natural disasters—earthquakes, volcanic eruptions, landslides, floods, and waterborne diseases—that are prevalent in Central America.

PURPOSE

A logical way to stimulate long-term economic growth and to promote the general well-being in Central America would be (1) to define known natural resources, (2) to assess the potential for discovering additional resources, (3) to identify the risks of natural disasters, and (4) to evaluate the status of institutions and programs dealing with these subjects in the region. Information on the current status of resources, hazards, institutions, and programs provides a starting point for considering appropriate ways to increase productivity, trade, investment, and employment.

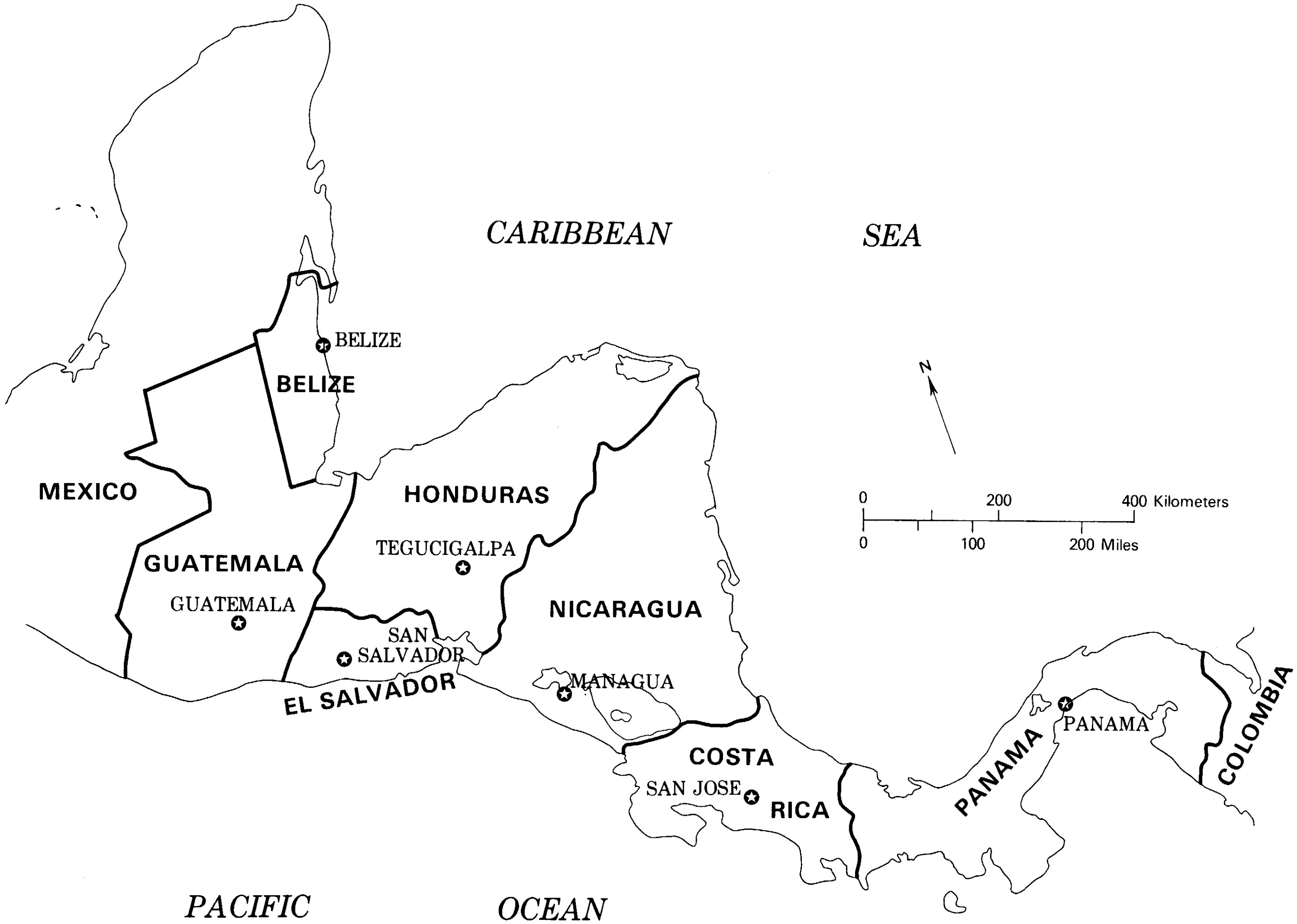

FIGURE 1. —Index map of Central America.

In recognition of the need for such information, the U.S. Geological Survey (USGS) has prepared this synopsis of the geologic and hydrologic framework—including mineral, energy, and water resources and geologic and hydrologic hazards—regionally and within individual Central American countries. It is hoped that the report will assist in formulating long-term development programs for the region. This synopsis is based in part on earth-science knowledge and experience acquired over more than 40 years of USGS involvement in Central America, mostly through bilateral assistance projects, joint research, and multilateral programs. Appendix 1 summarizes USGS activities in Central America and includes a bibliography of reports resulting from activities from 1940 to 1983.

This report also summarizes available information on the existing earth resources, institutions, and programs in Central America, including those with which the USGS is currently involved, and gives tentative projections of resource possibilities in the various countries. Appendix 2 lists names and addresses of agencies in Central American countries that deal with earth sciences and resources matters. Finally, this report focuses attention on the need for (1) current, reliable, good-quality, readily available resource information as a basis for encouraging capital investment, (2) regional efforts to mitigate the effects of geologic and hydrologic hazards, and (3) the importance of strengthening earth-science institutions and related programs.

SOURCES OF INFORMATION AND ACKNOWLEDGMENTS

Information and recommendations contained in this report are based in part on previous USGS investigations in Central America, in part on current activities and contacts, and in part on available published and unpublished materials from other sources. Recent compilations of regional geologic and resources information that have been especially valuable include a new geologic and tectonic map of Central America and the Caribbean region (Case and Holcombe, 1980), a new metallogenic map of North America (North American Metallogenic Map Committee, 1981; Guild, 1981a, b), and new plate tectonic and geologic maps of the northeastern part of the Pacific and adjacent areas compiled by the Circum-Pacific Map Project, an activity of the Circum-Pacific Council for Energy and Mineral Resources (Drummond and others, 1981, 1983). For petroleum resources, data from Petro Consultants, Ltd., were essential.

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GEOLOGIC AND HYDROLOGIC CONDITIONS, RESOURCES, AND HAZARDS IN CENTRAL AMERICA

GEOLOGIC FRAMEWORK AND EVOLUTION

Central America (Belize, Costa Rica, El Salvador, Guatemala, Honduras, Nicaragua, and Panama) consists mostly of a mountainous upland composed of a complex assemblage of rocks that accumulated over a period of several hundred million years. Geologic formations over much of the region are concealed by thick soil and dense forests, particularly on the slopes and lowland areas bordering the Caribbean Sea, where the tropical climate has produced dense jungle. Most of the population lives in the upland areas and in a narrow Pacific lowland belt. A chain of more than 80 active and dormant volcanoes reaches from the Mexican border to western Panama (fig. 2) along the Pacific side of Central America. Every country except Belize has some of this volcanic terrane.

The topography and earth resources of Central America are directly related to the geologic history of the North and South American continents and the Caribbean basin. In the northwest, the rocks and geologic structures making up all of Guatemala, Honduras, El Salvador, and northwestern Nicaragua represent southeastward extensions of those found in Mexico. At the southeastern end of Central America, the part of Panama east of the Canal Zone is the western extension of the Andes Mountains of the South American continent. The gap between these continental extensions, some 900 km, includes southwestern Nicaragua, all of Costa Rica, and western Panama. The rocks here are formed by younger volcanic processes.

The region now occupied by northern Central America was once a relatively shallow sea in which deposits of sand and mud accumulated and were later compacted to form sandstone, shale, and limestone. Some of these rocks were metamorphosed (recrystallized) by deep burial, compression, and heat. They are the oldest known rocks in Central America and are now exposed by erosion in much of Honduras, central Guatemala, and northern Nicaragua. Unmetamorphosed sedimentary rocks are exposed in large areas and numerous small basins mostly in northern Guatemala and Panama and in coastal lowlands generally bordering the Caribbean Sea.

Beginning about 15 million years ago, an episode of volcanism, accompanied by earthquakes caused by strong compressive stresses, began to form a land bridge

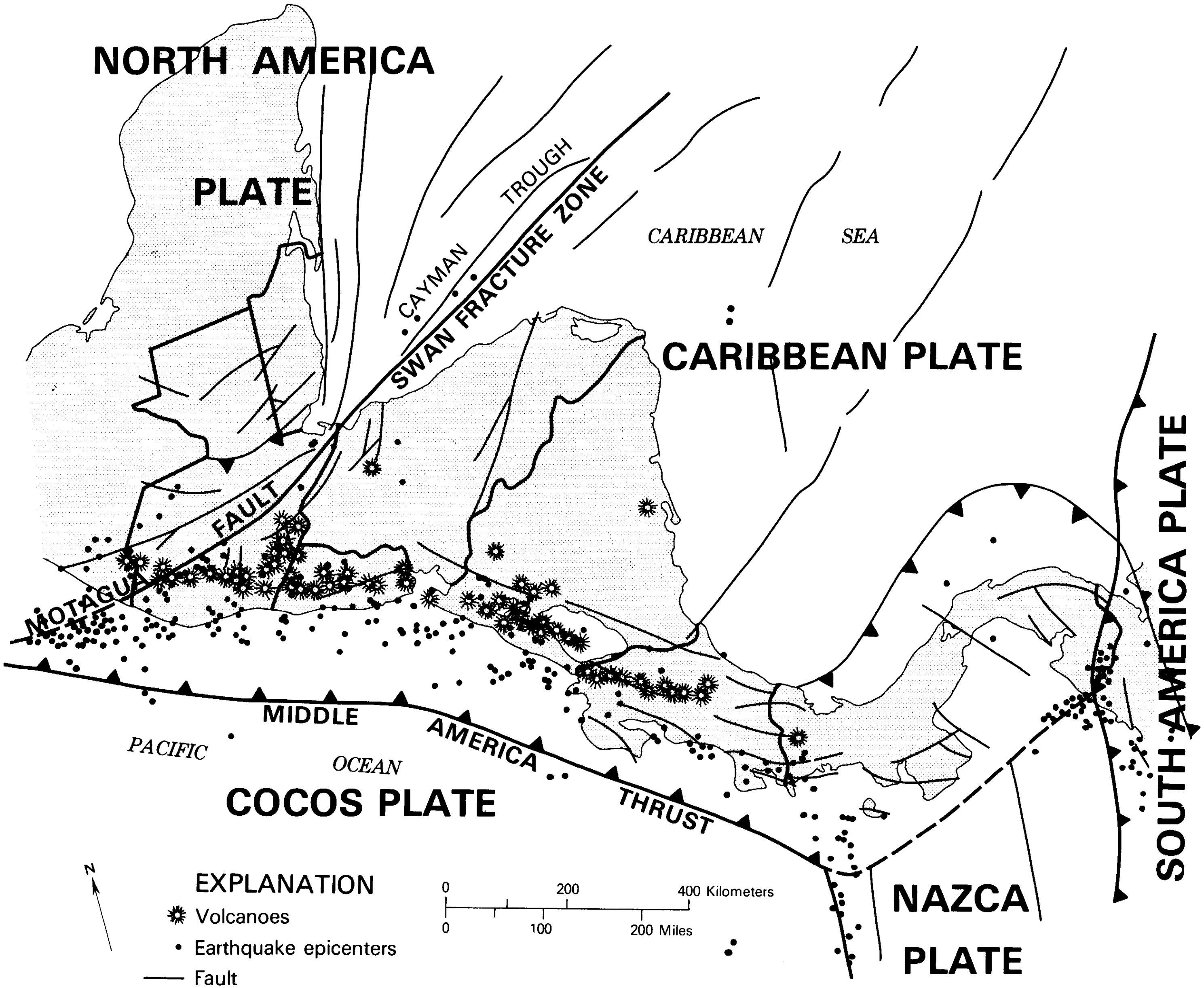


FIGURE 2. —Simplified tectonic map of Central America.

between North and South America by pushing up the sea floor between the continents. This geologic activity, which continues to the present time, makes Central America one of the most active volcanic and seismic regions on Earth. The time at which the Central American gap was closed is not known precisely.

The style of geologic evolution in Central America has resulted from the collision of large parts of the Earth's crust. The crust is broken into large, rigid segments or plates, which move extremely slowly but inexorably on a slowly deforming substratum. Where two plates collide, deformation and fracturing of the rocks take place and result in mountain-building and volcanic activity accompanied by earthquakes. In Central America, relative movement between the North American and the Caribbean plates is currently taking place along a fault crossing central Guatemala and extending eastward as the northern margin of the Caribbean basin (see fig. 2). In Guatemala, this fracture zone is called the Motagua fault; movement along this fault was the cause of the devastating 1976 earthquake in Guatemala.

When an oceanic plate composed of heavy rocks collides with a continental plate of lighter rocks, the heavier oceanic plate is usually forced beneath the lighter continental plate. The displacement of one plate beneath another creates a trench in the sea floor such as the one along the Pacific margin of Central America. As their depth increases, oceanic rocks become intensely heated and form molten rock (magma). Some of this magma may move upward along fractures and erupt at the surface to form a volcano or chain of volcanoes. Such is the case along the western side of Central America, where the Cocos plate, consisting of oceanic rocks in the Pacific, has collided with the Caribbean plate and plunged beneath that plate to form the long line of active and dormant volcanoes along the Pacific coast.

Locally, compression accompanying the collision of two plates causes melting at depth of parts of the continental-type rocks. This melting forms magma, which moves upward into the overlying rocks and solidifies as intrusions of light-colored igneous rock called granite. The granite may contain economically important metallic elements such as gold, silver, tin, beryllium, and lithium. In other places, masses of dark-colored ultramafic rock formed from heavier constituents in a magma chamber may be mechanically emplaced on land or along linear vents in the sea floor. These masses may contain other economically important metallic elements such as nickel, chromium, and platinum. The geologic processes outlined above commonly lead to a complex distribution of rock types and to a variety of geologic structures.

Rocks of the Central American countries can be grouped into the five major categories: (1) sedimentary rock (principally sandstone, shale, and limestone), (2) intrusive rock (granite and similar coarse-grained rock types), (3) volcanic rock (lava and ash), (4) ultramafic rock (peridotite, serpentine, and related rock types), and (5) metamorphic rock (schist, gneiss, quartzite, and other metamorphic rock types). Rocks in each category are potential hosts for specific mineral and energy resources and also have significance with regard to hydrologic, engineering, and land utilization capacities and problems.

MINERAL RESOURCES AND POTENTIAL

KNOWN RESOURCES

Central America has produced gold, silver, nickel, aluminum, copper, zinc, lead, antimony, iron, mercury, manganese, tungsten, and cadmium (fig. 3, table 1). The region also contains other metals of economic interest, including chromium, cobalt, titanium, molybdenum, and tin. Construction materials and industrial minerals such as sand and gravel, limestone, gypsum, sulfur, barite, marl, diatomite, cement, and salt are produced, generally for domestic consumption. In spite of the diversity of minerals present, the mineral industry directly contributes less than 3 percent (and in most cases less than 1 percent) to the gross domestic product of individual countries. Production of each mineral commodity is less than 1 percent of world production, with the exception of Guatemalan antimony, which has been about 1 percent (Martino and others, 1981).

Although the mining industry has not been an important factor in any Central American economy (Grunwald and Musgrove, 1970; Martino and others, 1981), the industry nevertheless has provided a continuing supply of exportable minerals and jobs at both large and small mines and support operations and might be expanded by the development of existing deposits and the discovery and development of new deposits. Development of existing large deposits and mines is related directly to world metal prices, labor costs, capital requirements, and interest rates. Development of small mines has certain advantages for less developed countries where unemployment rates are high in that it is labor intensive, requires less capital, takes advantage of small deposits, creates jobs in rural areas, and provides raw materials that can be used domestically (for example, construction materials and industrial minerals) or exported as a source of foreign exchange. A current overview of exploration and mining is given by Woakes and Carman (1983).

Central America has six world-class mines whose recent ore production exceeds 150,000 t/yr (table 2).

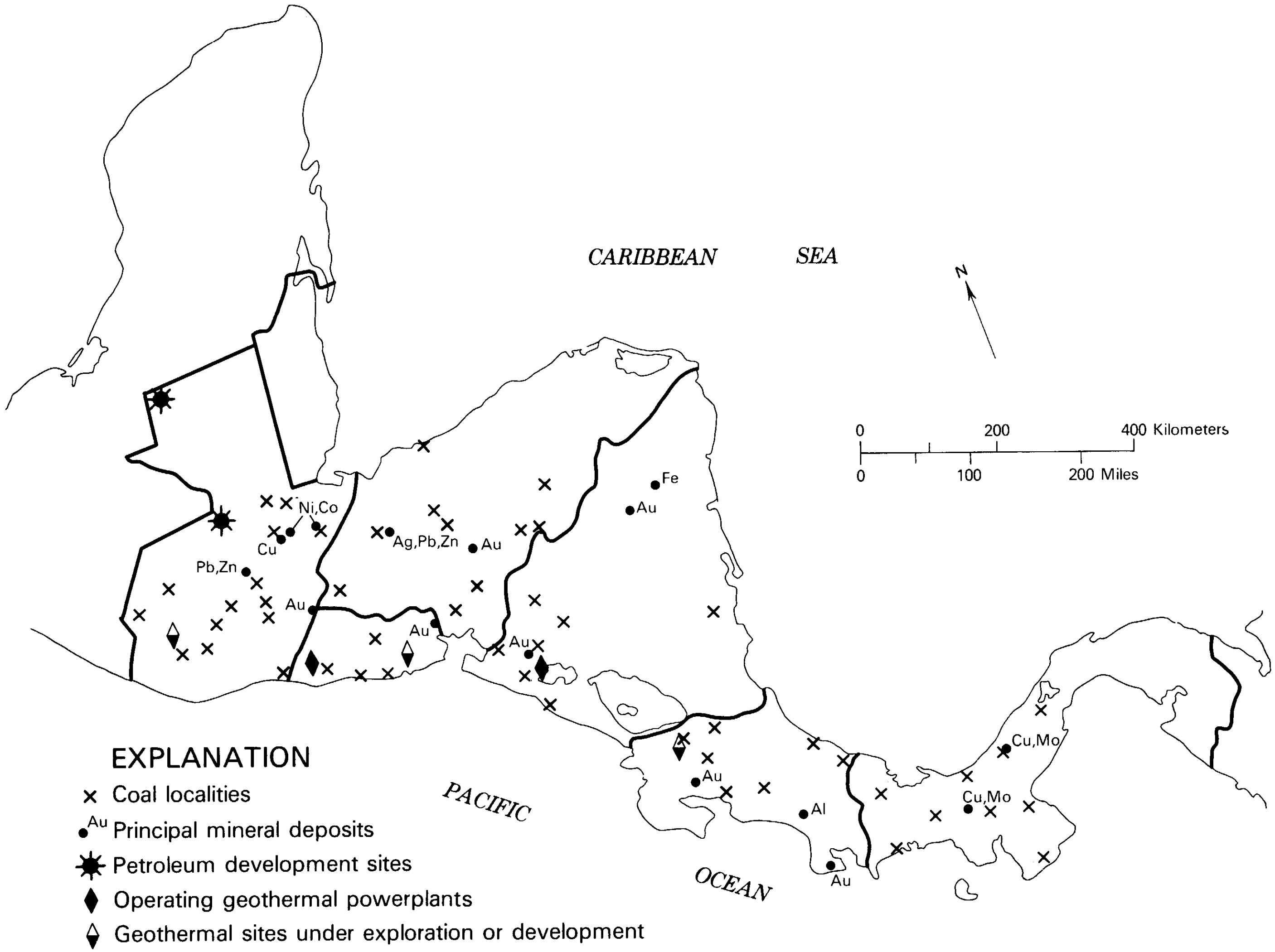


FIGURE 3.—Principal mineral and energy localities in Central America. Chemical symbols are identified in table 4.

TABLE 1.—*Mineral industry statistics for Central America (1981)*

[Modified from Ensminger (1983). t, metric ton; bbl, barrel; oz, troy ounce; m^3, cubic meter]

Country	Gross domestic product (1981 U.S. dollars)	Contribution to gross domestic product by minerals industry (percent)	1981 mineral industry production	Remarks
Belize	121 million	<1(?)	Limestone, 479,700 t; marl, 548,900 t; sand and gravel, 589,300 t.	No metallic minerals produced in 1981. Oil exploration but no production.
Costa Rica	4.7 billion	<1	Cement, 500,000 t; clay, 450 t; diatomite, 550 t; gold, 16,000 oz; lime, 7,000 t; salt, 1,100 t; silver, 1,500 oz; crushed rock and rough stone, 550,000 m^3; limestone, 50,000 t; sand and gravel, 200,000 m^3.	Major gold mine. Hydroelectric generating capacity to be increased. High priority to develop energy sources. Active coal assessment program.
El Salvador	3.4 billion	<1	Aluminum, 1,000 t; cement, 500,000 t; gold, 1,000 oz; gypsum, 6,000 t; iron and steel, 35,000 t; limestone, 500,000 t; salt, 20,000 t; silver, 110,000 oz.	Aggressive geothermal development program. Hydrocarbon production small.
Guatemala	3.15 billion	~1(?)	Antimony, 510 t; barite, 5,200 t; cement, 568,012 t; clay, 168,141 t; copper, 726 t; feldspar, 10,044 t; gypsum, 28,722 t; iron ore, 4,025 t; lead, 111 t; lime, 24,655 t; nickel, 5,000 t; crude petroleum, 1,800,000 bbl; pumice and ash, 20,451 t; salt, 13,679 t; silver, 8,000 oz; stone, sand, and gravel, 2,390,000 t; zinc, 2,996 t.	Major nickel plant recently closed. Major copper mine. Exports oil.
Honduras	2.7 billion	2.5	Antimony, 20 t; cadmium, 200 t; cement, 500,000 t; copper, 250 t; gold, 3,000 oz; gypsum, 20,000 t; iron and steel, 20,000 t; lead, 14,000 t; salt, 30,000 t; silver, 2,400,000 oz; limestone and marble, 500,000 t; zinc, 18,000 t.	Exports precious and base metals from major precious- and base-metal mine. New cement plant. Increasing hydroelectric generating capacity. Oil exploration active.
Nicaragua	2.9 billion	<1	Cement, 100,000 t; gold, 70,000 oz; gypsum and anhydrite, 30,000 t; lime, 30,000 t; salt, 18,000 t; silver, 167,000 oz.	Major gold mines. Limited petroleum exploration.
Panama	3.8 billion	~1(?)	Cement, 600,000 t; clay 99,624 t; salt, 15,000 t; stone, sand, and gravel, 2,560,000 t.	Major copper deposits

However, detailed descriptions and production information about smaller mining operations are not consistently published. Salas (1982, p. 189) reports that, in Latin American countries, there are many small-scale mining operations of less than 60,000 t/yr; in Mexico, for example, small mines account for more than 20 percent of total annual production.

Five countries (Costa Rica, El Salvador, Guatemala, Honduras, and Nicaragua) have produced most of the metallic minerals in Central America during the period 1977 to 1981 (table 3); all seven Central American countries have produced construction materials during the same period. Metallic mineral production has been inhibited in Central America (and elsewhere) by fluctuating metal prices, uncertainty about resource adequacy, world inflation, and rising energy costs.

TABLE 2.—*Central American world-class mines recently producing more than 150,000 t/yr of ore*

[Modified from Mining Magazine (1983)]

Country and mine	Production (1,000 t/yr) 150–300	300–500	500–1,000	Commodity
Costa Rica, Santa Clara		X		Gold
Guatemala, Oxec	X			Copper
Honduras, El Mochito			X	Zinc, lead, copper, gold, silver.
Nicaragua:				
Sententrion	X			Gold
Siuna			X	Gold
Vesubio	X			Zinc, lead, copper, gold, silver.

TABLE 3.—*Metallic minerals produced in Central America, 1977—1981*

[From Ensminger (1983). Production values represent mine output. No metallic mineral production is reported for Belize and Panama during the period 1977 to 1981. , production data for some countries and commodities for years indicated have not been available. Metal contents of ores and concentrates are in metric tons, unless otherwise noted]

	Costa Rica	El Salvador	Guatemala	Honduras	Nicaragua
Antimony	--	--	2,900	240	--
Cadmium	--	--	--	1,200	[3]
Copper	--	--	7,900	3,000	400
Gold[1]	77,000	12,000	--	12,000	330,000
Iron[2]	--	--	18,000	--	37
Lead	--	--	440	88,000	1,400
Nickel	--	--	19,000	--	--
Silver[1]	8,000	700,000	38,000	12,000	1,400,000
Tungsten	--	--	50	--	--
Zinc	--	--	7,000	110,000	14,000

[1]In troy ounces.

[2]Iron-ore tonnage.

[3]Small but undetermined quantity contained in zinc concentrates.

Development of the mineral industry in Central America has also been inhibited by the economic and political instability of the region.

A variety of metallic minerals is present throughout Central America, but many have not been produced. Table 4 shows the distribution by country of metallic elements in mineral deposits, as depicted on the Metallogenic Map of North America (North American Metallogenic Map Committee, 1981). Often, more than one metal is present in a deposit. The table shows that precious metals have been found in every country, whereas other commodities such as tin, chromium, and nickel have been found in only a few, probably because even small precious-metal deposits are highly profitable and are sought under the most difficult circumstances.

Although one mineral commodity (gold) has been mined in Central America since the 12th century, detailed knowledge of the geology and mineral resources of the region is sparse. Many deposits may be concealed by deeply weathered soil, dense tropical rain forests, or large areas covered by young, noneconomic sediments and volcanic rock. Nevertheless, a large part of Central America is known to be geologically similar to the mineral-rich Sierra Madre Occidental region of Mexico.

TABLE 4.—*Metallic mineral elements in mineralized areas of the Central American countries*

[From Guild (1981 a, b). Several metallic mineral elements are often reported from a single mineral deposit. --, no data]

	Belize	Costa Rica	El Salvador	Guatemala	Honduras	Nicaragua	Panama	Total
Gold (Au)	1	5	6	2	24	21	20	79
Silver (Ag)	--	3	6	7	15	8	1	40
Copper (Cu)	--	4	1	2	3	3	8	21
Lead (Pb)	--	6	1	8	3	2	1	21
Zinc (Zn)	--	6	1	8	4	2	--	21
Iron (Fe)	--	5	--	1	2	1	3	12
Titanium (Ti)	--	4	--	1	1	--	--	6
Aluminum (Al)	--	1	--	--	--	--	4	5
Manganese (Mn)	--	1	--	--	--	--	2	3
Molybdenum (Mo)	--	--	--	--	--	1	2	3
Antimony (Sb)	--	--	--	1	1	1	--	3
Cadmium (Cd)	--	--	--	1	1	--	--	2
Cobalt (Co)	--	--	--	2	--	--	--	2
Chromium (Cr)	--	--	--	2	--	--	--	2
Nickel (Ni)	--	--	--	2	--	--	--	2
Tungsten (W)	--	--	--	1	--	1	--	2
Mercury (Hg)	--	--	--	--	1	--	--	1
Tin (Sn)	1	--	--	--	--	--	--	1

A comparison of the number and types of mineral deposits of these two regions indicates that Central America should have additional mineral deposits and mineral commodities that could be developed.

Rocks and ore deposits of Central America are products of an active tectonic regime. The northern part of Central America is composed of large areas of relatively old igneous and metamorphic rocks, which contain deposits of silver, lead, antimony, mercury, and tin. The Motagua fault zone contains ultramafic rocks that originated several kilometers deep in the earth, along with associated deposits of nickel, chromium, and cobalt. Volcanic rocks that parallel the Pacific coast contain mineralized veins of gold, silver, lead, and zinc. Farther south, other volcanic rocks contain deposits of manganese. Some volcanic rocks are cut by intrusive rocks containing deposits of copper and molybdenum. Precious-metal deposits also occur in some places where sedimentary rocks have been intruded by igneous rocks. Mineral deposits in Central America tend to contain more silver and lead in the north and more gold and copper in the south.

RESOURCE POSSIBILITIES

Increasing the level of geologic knowledge about Central America should lead to the discovery of additional mineral resources. Concepts and technologies of mineral-resource evaluation, as well as those of the ore-forming processes, have evolved greatly in the past decade (Skinner, 1981). They can be applied to explore beneath the cover of young rocks and thick soil to find concealed deposits. Strategic and critical minerals, including the platinum-group minerals, and other metals such as gold, titanium, and the rare-earth elements may exist in heretofore unexplored geologic terranes. These terranes should be examined with modern exploration techniques, and the results should be evaluated in the light of recent concepts about ore-forming processes.

In Central America, as elsewhere, the types of rocks present and their geologic settings determine the kinds of mineral deposits (and thus the kinds of commodities) that may be present. By comparing the various geologic terranes in Central America with similar terranes elsewhere, applying the curent knowledge of geologic processes, and employing ore-deposit models (Erickson, 1982), one can make an estimate of the kinds and, in some cases, the amounts of metallic minerals that would reasonably be expected to be present.

One of the largest open-pit gold deposits in the western hemisphere (Pueblo Viejo in the Dominican Republic) was formed in volcanic rocks similar to those existing in Central America. Massive sulfide deposits containing zinc, lead, copper, gold, silver, and manganese deposits like those found in Cuba may exist in similar geologic terranes that are now covered by younger sedimentary and volcanic rocks. Phosphate deposits like those being mined in Florida are expected to be present but may be unrecognized because of the deeply weathered rock and thick soil. Heavy-metal-bearing sands containing platinum minerals (like those in Colombia), gold, tin, and rare-earth elements might be present in buried offshore beaches. Cobalt and tin are known to be present in Central America, but there is no information on the geologic environment of their occurrence. Unconventional mineral resources should not be overlooked; these include various metals in black shales, uranium in phosphate, various metals in coals, or byproducts of mining operations.

ENERGY RESOURCES AND POTENTIAL

OIL AND GAS RESOURCES AND EXPLORATION ACTIVITY

Geologic conditions in Central America are only marginally favorable for petroleum occurrences. Favorable areas are confined to those parts of the region that have adequate thicknesses of sedimentary rock and that contain favorable source and reservoir rocks. Oil and gas originate as products of the natural chemical alteration of organic materials. For a province to contain recoverable petroleum resources, those original organic materials must have been deposited in a poorly oxygenated environment and buried deeply enough for Earth temperatures to have fostered the chemical reactions necessary to form petroleum. Furthermore, once the petroleum had attained a liquid state, it must then have been able to migrate from the source rocks to a collecting area having reservoir properties favorable for accumulation and large enough for economic recovery. Thus, to have become petroleum producing, an area must have possessed source rocks, reservoir rocks, and geologic traps. Because migration of the oil from the source area to a reservoir is required, the time of formation of the trap and reservoir must have preceded that of the maturation of the organic matter and its subsequent migration into the reservoir as liquid petroleum.

For the Central American region as a whole, the most important limitation to petroleum development appears to be a lack of the geologic conditions necessary for the formation of suitable reservoirs. Information leading to this judgment has been derived from the several tens of wells drilled throughout the region, but not enough drilling has been done to be conclusive. The drilling has, however, provided considerable data on the maturity of potential source rocks. In many areas having sedimentary rock, the underground temperatures, down to drilling depths that are presently economically reasonable, have not been high enough to convert the organic matter to oil or gas. Information available at this stage of exploration in certain areas is therefore somewhat discouraging, but the continued and recent concession-taking and exploration activity conducted in most of the Central American countries by U.S. oil companies and those of other nations suggest that the region still holds potential for the discovery of economic oilfields (Deal, 1982).

Areas that might contain oil and gas resources are outlined on figures accompanying individual country descriptions; the seaward limiting boundary of economic operations has been set arbitrarily at the 200-m (650 ft) isobath. To date, commercial accumulations have been identified only in Guatemala. Shows of oil and gas, however, have been reported in the Limon Basin of Costa Rica near the Panamanian border on the Caribbean side and also offshore from Nicaragua where thick sedimentary rocks compose the Nicaragua Rise.

COAL RESOURCES AND POTENTIAL

Coal has been known in Central America since 1860, when a U.S. Navy expedition to Panama recorded several lignite beds of minable thickness on the northern coast. Since then, national agencies have accumulated resource data demonstrating the presence of coal, including lignite, in every Central American country except Belize. As energy needs expanded in these developing countries during this century, demands were met largely by inexpensive imported oil. As a result, although more reports of coal have become known, no substantive effort has been made to study the potential for coal exploitation until very recently, when the cost of imported oil increased dramatically. Several Central American countries are now considering coal as an alternative source of energy and are starting programs to determine if any of their coal deposits are of sufficient quality and quantity to merit exploration and development.

In most localities, the number of coal beds is unknown, but 11 beds are reported at one locality in Guatemala, and 8 are reported at one locality in Panama. The sulfur and ash contents are also generally unknown, but reported values range from low (<1 percent) to high (>15 percent) for sulfur and medium (>8 percent) to high (>15 percent) for ash. None of the Central American coal deposits is known to contain coal of high enough rank to qualify as coking coal.

A preliminary unpublished estimate of Central American coal resources made by G.H. Wood, Jr., of the USGS totals 355 million short tons (identified and hypothetical). This figure is, however, considered to be minimal because no data are available on which to base an estimate for many of the reported localities.

Lignite, which constitutes most of the reported coal deposits in Central America, is not the most desirable of fuels, yet it is used in many parts of the world, especially for the production of electricity. Until the results of preliminary investigations into numerous reports of coal occurrences in Central America are available, it is not possible to predict how viable a substitute for petroleum the coal deposits of the region may be. Bohnenberger and Dengo (1978) have concluded "a systematic campaign to evaluate the carbonaceous beds of Central America should be carried out. . . . The results of such a program would be extremely valuable for a regional evaluation." In light of the many known coal occurrences and given the possibility of additional unknown occurrences, it would indeed be surprising if at least a few of these deposits did not prove to be exploitable. The known occurrences of coal are shown on individual country maps. In addition, new technology is proving that the conversion of peat to methanol (a form of alcohol) for the generation of energy is economically viable. There has been no interest in and no exploration for peat deposits in Central America to date, but it is very probable that peat deposits exist.

GEOTHERMAL RESOURCES AND POTENTIAL

Central America is ideally situated with regard to geothermal energy potential. Despite its relatively small geographic extent, the region contains active segments of five major tectonic plates. Young volcanic centers concentrated along zones where these shifting plates abut against or grind slowly past one another provide deep heat sources for overlying geothermal systems. Thus, the region's numerous volcanic centers present prospective target areas for geothermal exploration and development.

Emphasis on the development of geothermal energy in Central America probably will continue to concentrate on electric power generation rather than nonelectric direct uses. Several geothermal fields capable of supporting electrical generating plants have already been identified, and many other undiscovered systems undoubtedly exist. Development of these geothermal resources for electrical generation, in conjunction with the development of other indigenous energy resources, may significantly decrease Central America's dependence on imported oil. Presently, El Salvador's 95-MW geothermal plant produces about 25 to 44 percent of the country's electricity, and Nicaragua's newly opened 35-MW plant provides 12 percent of its electricity.

Nearly every country in the region has conducted geothermal exploration programs. In addition, the Latin America Energy Organization has sponsored major conferences on geothermal exploration since the late 1970's and has carried out major reconnaissance and predevelopment feasibility studies. Some of the more developed countries (for example, the United States, Japan, Italy, Iceland, France, Great Britain, and New Zealand) have participated in these conferences and (or) provided funding and technical assistance for development programs.

WATER RESOURCES AND HYDROLOGIC CONDITIONS

Precipitation throughout Central America ranges from 500 to 7,500 mm/yr (20–295 in./yr), the average being 2,500 mm (100 in.). Yearly totals range widely from place to place; drier coastal areas receive less than 500 mm (20 in.), and the wet interior mountains receive as much as 7,500 mm (295 in.). The region has pronounced wet and dry seasons (fig. 4). From May to October, rainfall is abundant; January, February, and March are dry. Because of the easterly trade-wind flow, the Caribbean coast and the east-facing slopes of mountains receive the heaviest rain. Caribbean hurricanes are a threat to the region from Costa Rica northward. Pacific hurricanes are less of a threat because they generally turn north before reaching the western coast.

Water supply for basic human needs is without question the most severe water problem in Central America. Problems exist in both urban and rural areas. Waterborne diseases are the greatest killer, and dysentery is the major cause of infant mortality. Contamination of surface-water supplies is widespread, and there are cases of deterioration in the quality of ground-water supplies (United Nations, 1976). These conditions are frequently aggravated by drought.

Despite the abundance of rain over most of the region, water availability is a frequent problem (United Nations Educational, Scientific, and Cultural Organization, 1982; Bulkley and others, 1965). Natural variability in the yearly rainfall cycle can have strong impact on rainfed agriculture. For example, a delay in the onset of the rainy season in Honduras almost always brings severe drought to the south and west (U.S. Agency for International Development, 1982). There is good potential throughout the region for alleviating the impact of surface- and ground-water resources (Patchick, 1968).

Extensive clearing of tropical forests for grazing lands has resulted in severe erosion and flooding problems. The dense vegetation and tropical climate result in high evaporation rates throughout the year. Because watersheds are small, drought conditions can occur during even moderately extended dry seasons and cause severe disruption in water supplies for domestic, industrial, and agricultural areas. These problems are aggravated by infrastructure deficiencies and lack of capital for investment in structures and nonstructural solutions.

Water is also necessary to support mining operations. However, mining often reduces the quality of the water used either directly (for example, in washing operations) or indirectly (for example, natural seepage from tailings exposed to the atmosphere may result in pollution of both ground and surface water).

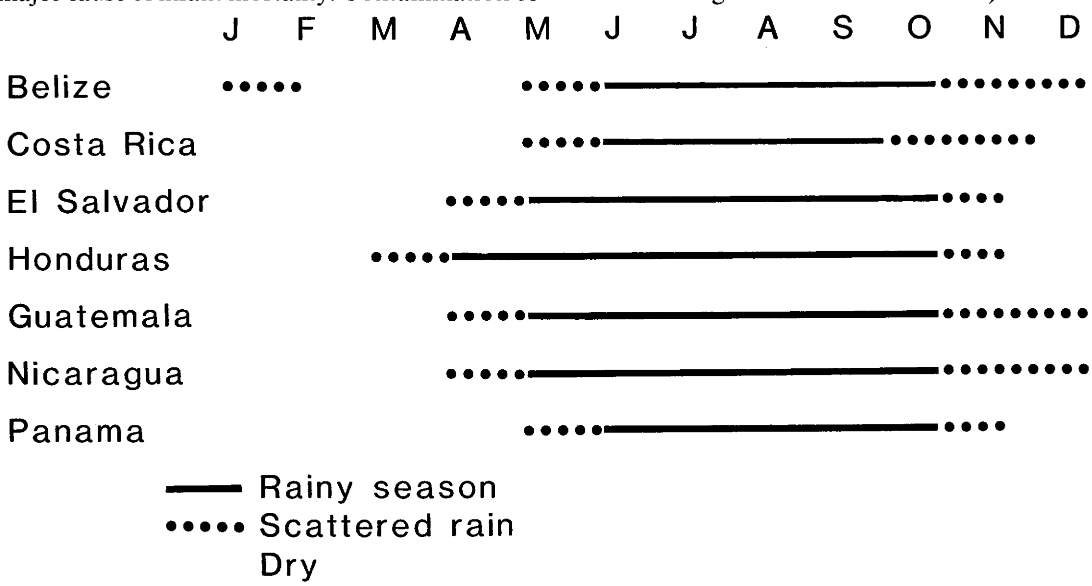


FIGURE 4.—Rainfall distribution in Central America. The Caribbean coast generally receives heavier annual rainfall owing to the prevalence of the easterly trade winds. Rain shadows generally occur on the western slopes of the high mountain ranges.

Industrial water needs will continue to grow as capital investments are made in the region. Water-conservation measures will need to be introduced simultaneously to prevent adverse impacts on current water supplies (United Nations Development Program, 1981).

The mountainous topography and abundant rainfall of Central America provide an excellent setting for hydropower development. A number of countries in the region have developed hydropower resources that supply the major portion of their electric power needs. Much potential is reported (U.S. Agency for International Development, 1982), but development should proceed only after careful study of regional water-resources availability, particularly with regard to the magnitude and variability of river flows and sediment loads.

A strong need exists for basic data on streamflow and sediment-discharge and rainfall-runoff relationships; these data will lead to programs for minimizing adverse effects and maximizing beneficial impacts, particularly with regard to flood control, reservoir management, and hydropower development.

The most critical water issues for Central America are shown in table 5, and some specific water problems are shown in table 6. The conclusion to be drawn about hydrologic conditions in these tropical countries is that the typical spectrum of water-resources problems exists; the challenge is to solve these problems through assessment and wise capital investment.

GEOLOGIC AND HYDROLOGIC HAZARDS

The many earthquakes and volcanic eruptions that occur in Central America produce geologic hazards that are a constant and significant problem for a substantial percentage of the population. Most of the destructive earthquakes occur in topographic depressions that lie along the general trend of the volcanoes, in depressions formed by transverse breaks in the volcano trend, or in river valleys that follow major plate-bounding faults (fig. 2). All of these areas are also the sites of major population centers. The great damage and loss of life caused by these earthquakes are directly attributable to their shallow focus, their location in areas of low relief where cities are commonly situated, and their subsequent triggering of massive landslides. More than 80 active or geologically young volcanoes are concentrated in a 600-km-long belt that extends nearly the length of Central America. These volcanic centers provide sources of deep heat for overlying geothermal systems, but potential future eruptions pose hazards to nearby communities and geothermal installations.

TABLE 5. —*Most critical water issues in Central America*

HAZARDOUS WATER PROBLEMS
1. Flooding
2. Droughts
3. Landslides and mudslides
4. Hurricanes

WATER PROBLEMS
1. Poor surface-water quality
2. Poor ground-water quality
3. Limited ground-water resources
4. Water logging

WATER FOR DEVELOPMENT
1. Domestic supply and sanitation
2. Hydropower
3. Agriculture (food and fiber)
4. Mining
5. Navigation

BASIC SUPPORT NEEDS
1. Specialized expertise
2. Equipment
3. Funds for operation and maintenance
4. Infrastructure and institution building
5. High tech

TABLE 6.—*Some specific water problems in Central America*

[Data from United Nations (1980)]

	Belize	Costa Rica	El Salvador	Guatemala	Honduras	Nicaragua	Panama
Flooding	X	X	X	X	X	X	
Droughts		X	X	X	X	X	X
Surface-water and ground-water contamination.	X	X	X	X	X	X	X
Erosion and sedimentation	X	X	X	X	X	X	X
Poor natural ground-water quality.	X				X		
Ground-water quantity limited by geology.			X		X	X	X
Aquifers overdeveloped	X	X	X	X	X	X	X
Saline water encroachment			X		X	X	X
Waterlogged land	X	X					X

Floods cause severe damage throughout the region. Their major causes are hurricanes and heavy rains associated with tropical disturbances that move onshore from the Caribbean. In areas that have been deforested, floods are especially severe and are accompanied by destructive erosion and, in some cases, by earth flows and mudslides. Because rainfall is variable, the region is also subject to frequent drought. As recently as May 1983, Tegucigalpa, the capital of Honduras, was suffering from an acute water shortage caused by a delay in the onset of the rainy season.

Clearly, geologic and hydrologic hazards are natural and continuing phenomena that man must study, understand, and prepare for if he wishes to live and prosper in Central America.

STATUS OF EARTH AND WATER RESOURCES IN THE CENTRAL AMERICAN COUNTRIES

BELIZE

STATUS OF GEOLOGIC AND HYDROLOGIC INFORMATION AND PROGRAMS

Detailed geologic maps of Belize do not exist, but generalized geologic maps are available (Bonis and others, 1970; Case and Holcombe, 1980). Generally flat-lying, unmetamorphosed sedimentary rocks extend south and east from Mexico and Guatemala and cover about 80 percent of Belize. The Maya Mountains, located near the middle of the country, are composed of older metamorphic, intrusive, and volcanic rocks. Little information is available on mining or mineral exploration in Belize, and mineral production appears to have been limited to building materials, sand and gravel, limestone, and marl. No hydrologic maps of the country have been published.

MINERAL RESOURCES AND POSSIBILITIES

Geologic exploration and mapping of Belize appear to have been discouraged by the lack of a mining history and by dense tropical jungle. Occurrences of gold, tin, copper, lead, zinc, and barite have, however, been reported (Bateson and Hall, 1977; Guild, 1981a, b; Weyl, 1980). Belize is the only Central American country to have a reported occurrence of tin (fig. 5). Molybdenum, lithium, beryllium, and tungsten typically occur with tin, and this association should be examined.

ENERGY RESOURCES AND POSSIBILITIES

Oil seeps have been reported, and an offshore test well reported shows of oil in 1981. There is no oil production at present; however, three U.S. companies have done drilling or surface exploration in Belize as recently as 1981, and two wells were drilled in 1982. In 1982, there were 24,838 km^2 held under lease. Sedimentary formations in Belize are eastern extensions of those of the Chapayal-Peten Basin of Guatemala, where two small fields have produced oil since 1974 and 1977. This fact, combined with the knowledge that the Mexican part of this same general geologic province contains the prolific Reforma district (in a different geologic setting), encourages continued onshore and offshore exploration.

Belize is the only Central American country in which coal or lignite has not been reported (fig. 6), possibly because of a lack of exploratory efforts. It is possible that coal or lignite may occur in the extreme south of Belize in formations corresponding to those reported to be coal bearing nearby in Guatemala. Because Belize is remote from the belt of young Central American volcanoes, high-temperature geothermal resources are less likely to be discovered.

WATER RESOURCES

Belize, like most countries in Central America, has abundant water resources. The subtropical climate of Belize is affected by its topography and seasonal trade winds from the Caribbean. Precipitation varies geographically from about 1,300 mm/yr (51 in./yr) at Corozal along the coastal plains to as much as 4,450 mm/yr (175 in./yr) at Feleko in the Mayan Mountains. Precipitation also varies seasonally, as much as 80 percent of the annual total occurring from June to October. The principal rivers in the country (fig. 7) are the Hondo, the New, and the Belize, which is navigable in its lower reaches. These rivers and others offer untapped hydroelectric potential.

The main hydrologic problems in Belize are related to hurricanes, water supply, water quality, and overall water-resources management. Hurricanes affect Belize frequently (six since 1931), causing severe damage and extensive flooding. Less than 50 percent of all households in the country are connected to potable water supplies. Lack of sewerage facilities results in discharge of wastes to streams and consequent contamination of surface and ground water. The quality of ground water is also affected in some areas by high concentrations of sulfate and calcium-magnesium, which increase hardness.

The country needs funds for equipment and training of personnel to conduct in-depth water-resources investigations.

COSTA RICA

STATUS OF GEOLOGIC AND HYDROLOGIC INFORMATION AND PROGRAMS

Although geologic maps and information for Costa Rica are more extensive than those for some other Cen-

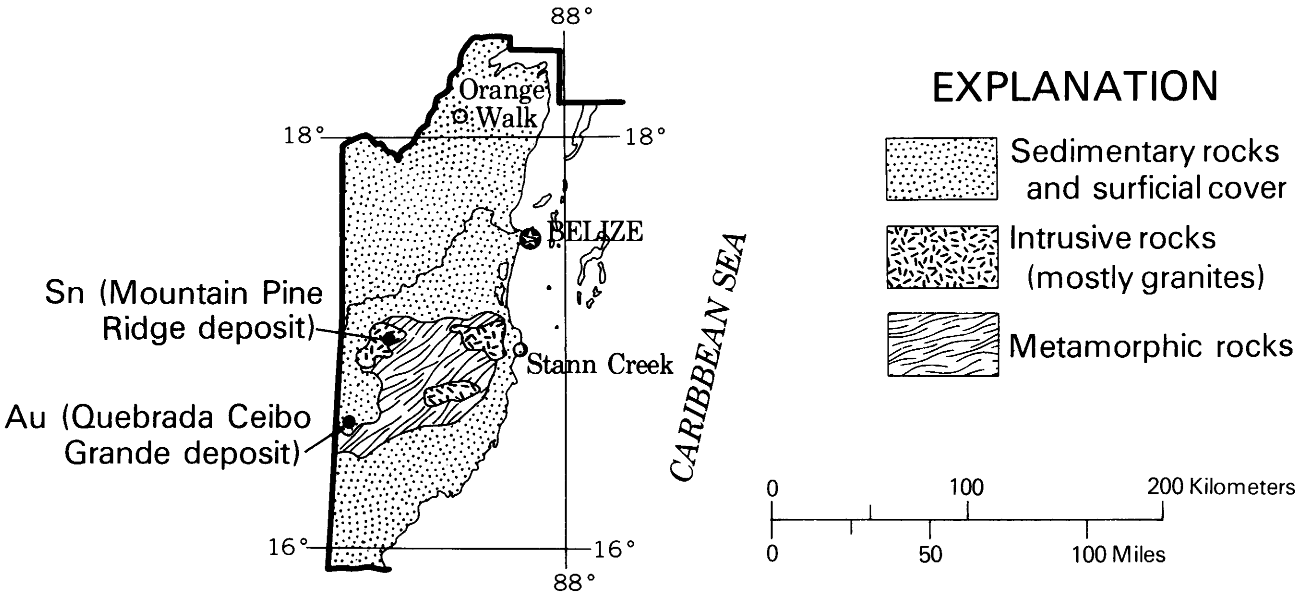


FIGURE 5. —Major geologic divisions and principal mineral deposits in Belize. Geology simplified from Case and Holcombe (1980). The metals contained in deposits are indicated by chemical symbols. Locality names are in parentheses.

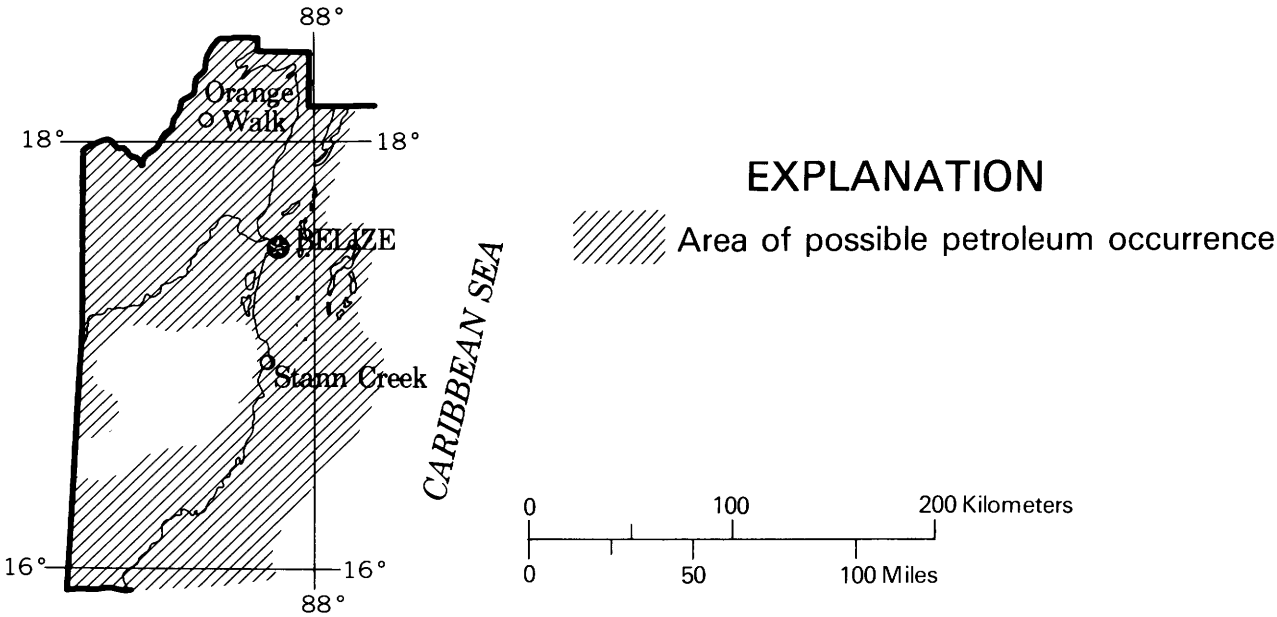


FIGURE 6.—Energy resource potential in Belize. The seaward boundary is defined by the 200-m isobath.

tral American countries (Weyl, 1980, p. 324–329), the most recent known compilation was made in 1968 (Dondoli and others, 1968). Volcanic rocks of both continental and marine origin occupy about half of northern Costa Rica, which is dominated by the active volcanoes Irazu, Poas, and Turrialba. These volcanic rocks overlie or are interbedded with sedimentary strata, mostly of marine origin, which crop out over most of the southern part of the country. Granitic rock bodies are present along the axis of the southern mountain region of the country, and one ultramafic body has been reported along the Pacific coast.

MINERAL RESOURCES AND POSSIBILITIES

Gold is the principal metal produced in Costa Rica, but various industrial minerals and construction materials are also mined (see table 1). The Santa Clara open-pit gold mine (fig. 8) is ranked world class (Mining Magazine, 1983). Silver, lead, and zinc ore deposits are reported in close proximity to some gold deposits. Undeveloped deposits of aluminum, copper, manganese, and iron- and titanium-bearing sands have also been reported.

It seems likely that additional deposits of gold, silver, copper, lead, zinc, and other metals may be discovered if more extensive mapping and geochemical and geophysical surveys are carried out, especially in the northwest and south. The ultramafic rocks should be evaluated for nickel, chromium, and platinum-group mineral content. Possibilities for phosphate should also be investigated in the sedimentary rock sequences, especially in those of Cretaceous age, which have showings of phosphate in Nicaragua.

ENERGY RESOURCES AND POSSIBILITIES

Although oil and gas have not yet been found in economic quantities in Costa Rica, producible amounts may exist on both sides of the country. On the Caribbean side, the Limon Basin, which appears to be a southward extension of the Nicaragua Rise, has showings of oil at depths of 1,220 to 1,520 m (3,880 to 4,840 ft) in holes drilled onshore. The most favorable region, judging by the amount of industry exploration, appears to be near the Panamanian border. On the Pacific side of the country, where a narrow offshore basin exists, applications for concessions have been submitted, but no records of

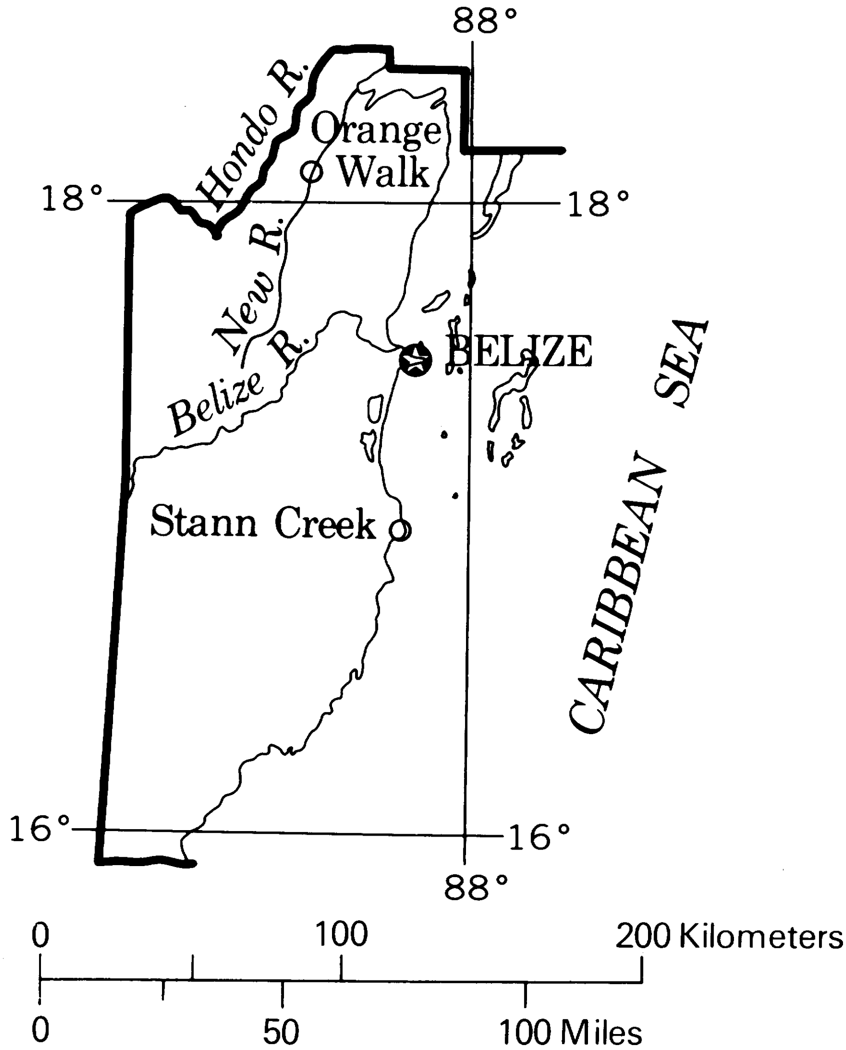


FIGURE 7.—Major surface-water features of Belize.

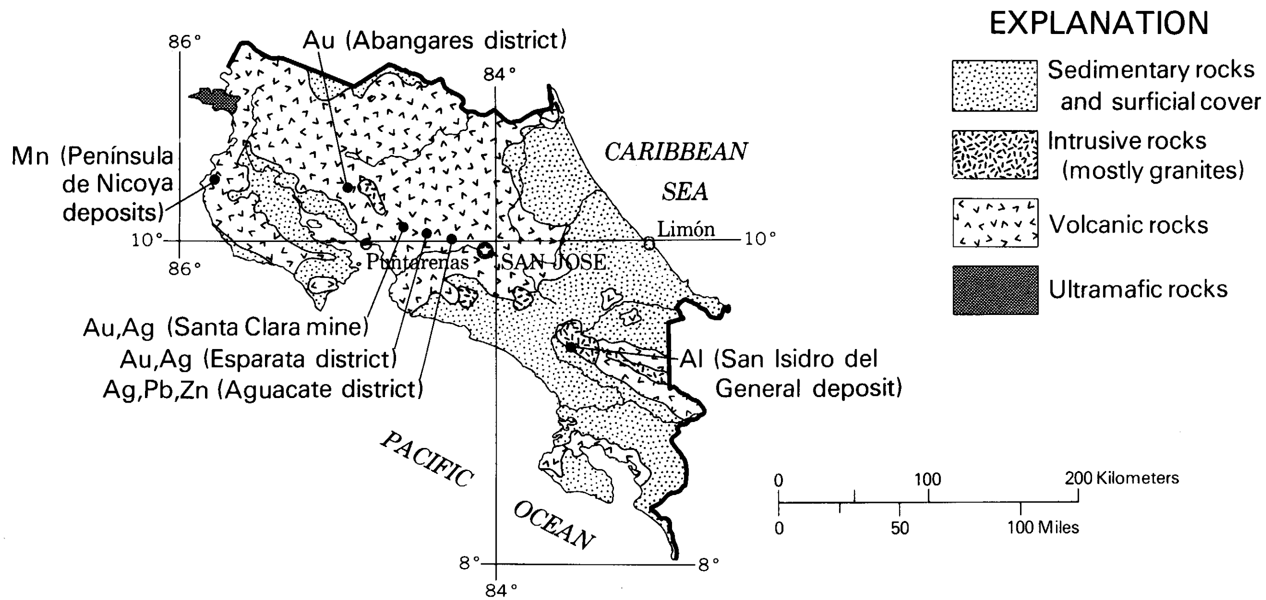


FIGURE 8. —Major geologic divisions and principal mineral deposits in Costa Rica. Geology simplified from Case and Holcombe (1980). The metals contained in deposits are indicated by chemical symbols. Locality names are in parentheses.

exploration have been reported. Relatively high heat flow in that area enhances the potential for petroleum.

Coal has been reported at a number of localities in Costa Rica (fig. 9). One of these localities is the Volio deposit in the east-central corner of the country, about 3 mi from the Panamanian border. A project to explore and appraise this deposit is in the planning stages; USGS and the Bechtel Corporation will provide assistance, under the auspices of USAID. Results of preliminary investigations are encouraging, but detailed mapping, drilling, sampling, and analysis of the coal beds will be needed to resolve the complex geologic structure and to determine the minable reserves. The coal that occurs in the Volio deposit is in beds 1 to 2 m thick and appears to be subbituminous and of good quality. Other coal localities have not been examined sufficiently to determine whether similar exploration and appraisal programs would be warranted.

WATER RESOURCES

The climate and hydrology of Costa Rica vary across its three distinct physiographic regions (the Caribbean watershed, the Central Mountains, and the Pacific watershed). Precipitation varies from about 1,300 mm/yr (50 in./yr) on the coast to as much as 7,500 mm/yr (295 in./yr) in the Central Mountain Range. Although hurricanes rarely affect the country, monsoon rains cause frequent damaging floods (three major floods since 1970). Rivers abound throughout Costa Rica (fig. 10), the principal ones being the San Juan, the Tempisque, and the Sixaola (U.S. Army Corps of Engineers, 1965).

Ninety-eight percent of the electric power presently generated in Costa Rica is hydroelectric. Additional hydroelectric potential of more than 10 times the present production has been estimated. Geothermal potential has also been identified. Ground-water supplies are abundant and generally of excellent quality for most uses.

Hydrologic problems in Costa Rica include flooding, droughts, surface- and ground-water contamination, waterlogged land, and overdevelopment of key aquifers. Costa Rica has developed some elements of the infrastructure necessary to resolve some of these problems.

Some trained staff and laboratory facilities are available. Additional support is required to train scientists and technicians, acquire modern equipment and instrumentation, and develop selected areal and countrywide investigations.

GEOLOGIC AND HYDROLOGIC HAZARDS

Like its Central American neighbors, Costa Rica has a historical record of severe earthquakes. As recently as 1973, a large earthquake claimed 23 lives. Earthquake-triggered failures of mountain slopes were the cause of all deaths and injuries. Landslides and debris flows gener-

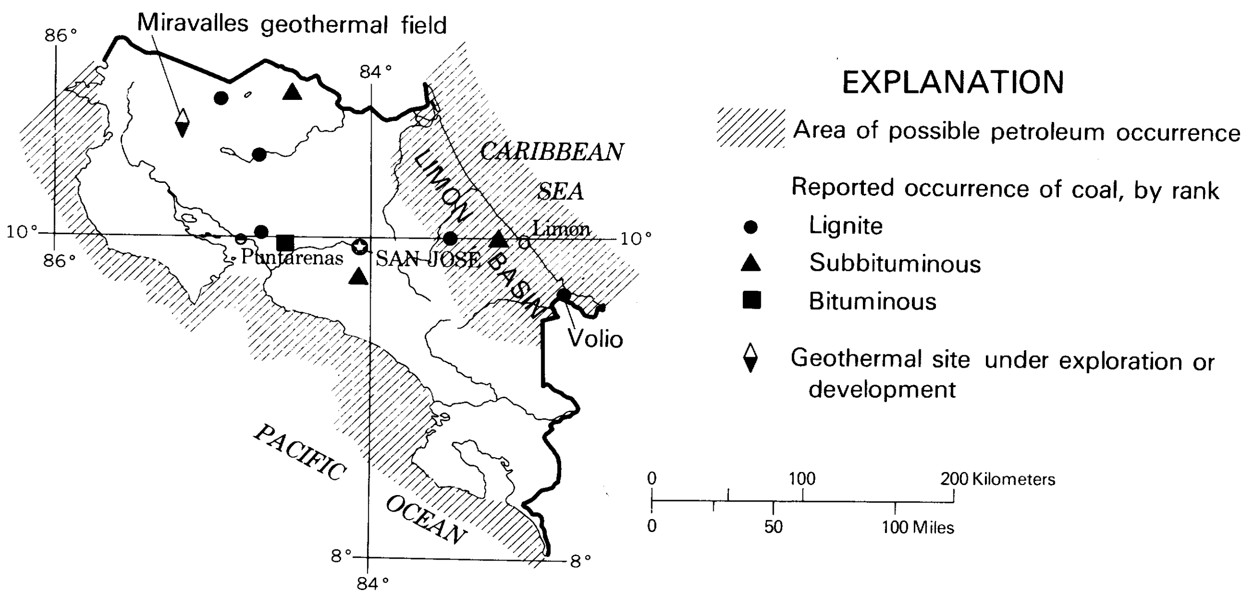


FIGURE 9.—Energy resource potential in Costa Rica. The seaward boundary is defined by the 200-m isobath.

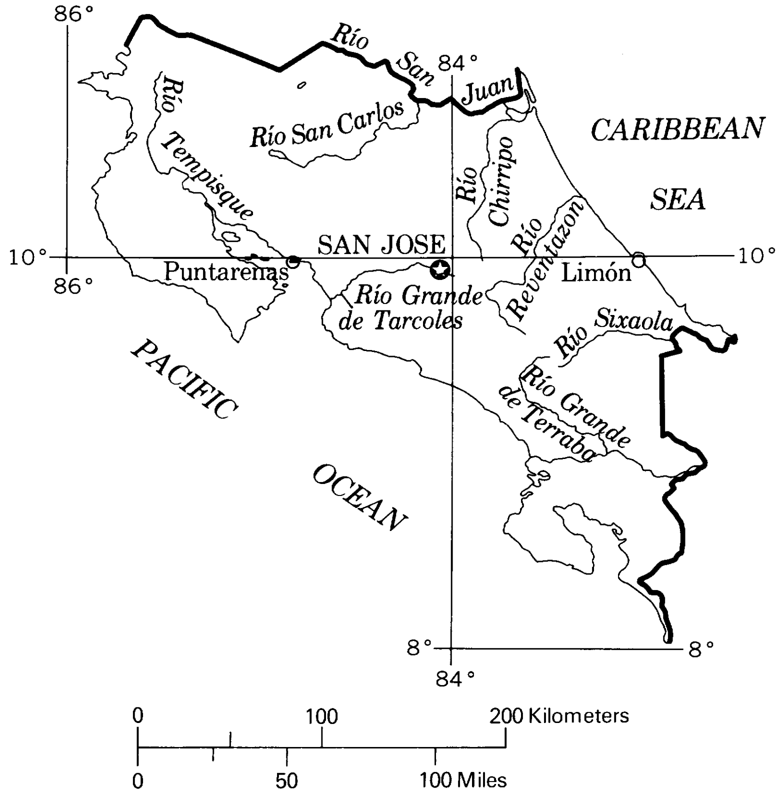


FIGURE 10.—Major surface-water features of Costa Rica.

ated by earthquakes are a common hazard throughout Central America.

Volcanic eruptions are also a major geologic hazard in Costa Rica. Arenal, a volcano in northwestern Costa Rica, erupted explosively in 1968, killing 78 people. Irazu, a volcano in the Central Cordillera of Costa Rica, erupted from 1963 to 1965, destroying several coffee plantations and covering San Jose and Cartago with ash.

Geologic hazards may cause hydrologic hazards, as the eruption of the volcano Irazu did, when the ashfall polluted the water supplies of San Jose and other cities of the Meseta Central.

GEOTHERMAL ENERGY

Costa Rica's geothermal area extends for about 30 km along the flank of the chain of young volcanoes. The geothermal development program in Costa Rica is focused on the geothermal field near Miravalles Volcano. An initial survey of about 2,000 km^2 defined this area as the most promising in Costa Rica, and three deep exploration-production wells were drilled during 1979 and 1980. On the basis of high reservoir temperatures (230°–245°C) and favorable flow test results, the Instituto Costarricense de Electricidad plans to begin development at this site by building a 25-MW geothermal plant.

EL SALVADOR

STATUS OF GEOLOGIC AND HYDROLOGIC INFORMATION AND PROGRAMS

Geologic maps of El Salvador at various scales have been published principally by the Federal Republic of Germany (Bundesanstalt fur Geowissenschaften und Rohstoffe, 1976–1978; Weber and others, 1974).

Volcanic mountain ranges containing active volcanoes extend over about 80 percent of the country. Sedimentary rocks, mostly sandstones and limestones, are intruded by igneous rocks. In addition, thick deposits of sedimentary rocks that were formed in ancient lakes are present in the Lempa Valley. The Government of El Salvador began a $1.5 million geological program in 1981 to locate mineral deposits. Results of this study have not been published.

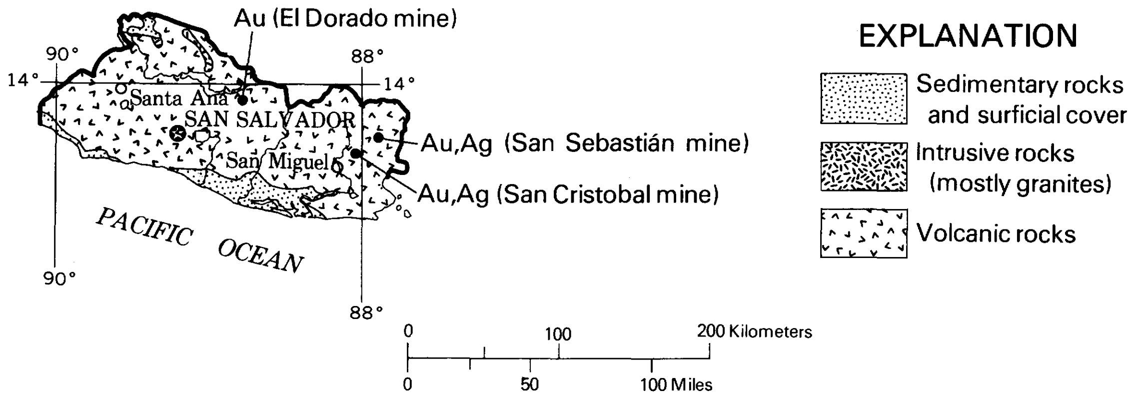


FIGURE 11.—Major geologic divisions and principal mineral deposits in El Salvador. Geology simplified from Case and Holcombe (1980). The metals contained in deposits are indicated by chemical symbols. Locality names are in parentheses.

MINERAL RESOURCES AND POSSIBILITIES

In 1981, El Salvador produced an estimated 1,000 troy ounces of fine gold together with an estimated 110,000 troy ounces of fine silver from its precious-metal mines (fig. 11). Gold production was down from a high of 3,619 troy ounces in 1978; silver was down from a 1978 high of 185,000 troy ounces. Other mineral commodities produced were limestone and cement (table 1). Iron- and titanium-bearing sands are known to exist along the coast (Weyl, 1980). Silver, lead, and zinc deposits should be explored for along the concealed contacts of limestones and younger intrusive igneous rocks. The lake deposits should be examined for the possible presence of amber, which occurs in similar deposits in the Dominican Republic.

ENERGY RESOURCES AND POSSIBILITIES

No exploration for oil and gas in El Salvador has been reported, and no rights were held in 1982. The most recent known exploration, sponsored by the United Nations, consisted of seismic survey work over the Pacific shelf area (fig. 12) in 1974. The only area of the country that is at all prospective is that part of the narrow Pacific shelf shared with Nicaragua to the south. However, here the regional geologic conditions are not very favorable.

El Salvador consists mostly of volcanic rocks that normally do not contain deposits of coal or hydrocarbons. Five lignite deposits are reported in intermontane basins containing very young sediments containing organic matter. They warrant systematic evaluation (Bohnenberger and Dengo, 1978), particularly because they constitute a combustible fuel.

WATER RESOURCES

El Salvador has less abundant water resources than its neighboring countries. The varied physiography of the country results in a tropical climate; the average annual precipitation is about 1,830 mm (72 in.). Precipitation increases with elevation, from about 1,500 mm (59 in.) at the coastal plains to as much as 2,300 mm (90 in.) in the mountain ranges. About 95 percent of the rainfall occurs from May to October; frequent severe droughts occur during the drier months. The main rivers in the country (fig. 13) include the Lempa and the San Miguel. Intermittent streams abound in the country.

The principal hydrologic problems in El Salvador are related to overdevelopment of aquifers, droughts, surface- and ground-water contamination, and limited water-resources data. The geology of the country limits the extent and productivity of the aquifers (Seeger, 1962). Although ground water is generally of good quality, overdevelopment is already evident near San Salvador and in coastal areas. Unsewered facilities offer the potential for contamination of both ground- and surface-water supplies.

Although water-resources data acquisition has improved recently, El Salvador needs technical, managerial, and financial support.

GEOLOGIC AND HYDROLOGIC HAZARDS

Severe earthquakes have had a major impact on El Salvador. Moderate-sized shallow earthquakes have destroyed or severely damaged San Salvador, the capital, 14 times. Because of their shallow origin, many

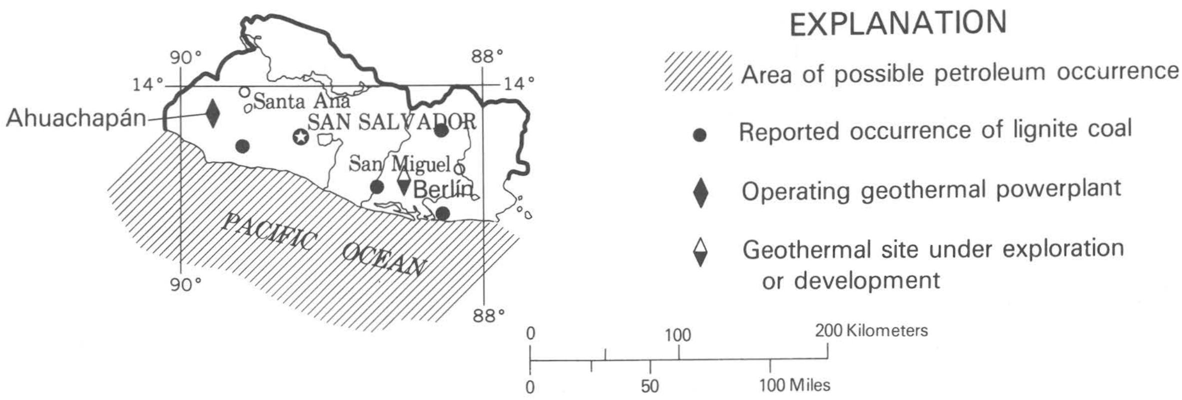


FIGURE 12. —Energy resource potential in El Salvador. The seaward boundary is defined by the 200-m isobath.

earthquakes have damaged a few closely spaced population centers but caused little damage to others nearby. Most of the earthquakes have occurred in the longitudinal depression that parallels the trend of volcanoes. A major seismic zone that has been seismically quiet for shallow events since 1950 has been identified along the coast of El Salvador. It has been suggested that this zone may be the site of a major earthquake in the near future.

Volcanic eruptions are a continuing hazard for the citizens of El Salvador. New volcanoes such as Izalco have formed in historic time. San Salvador is located at the foot of Boqueron Volcano, which erupted with accompanying earthquakes in 1659 and 1917. Lake Ilopango on the eastern outskirts of San Salvador (fig. 13) occupies a huge volcanic depression (caldera). Landslides accompanying volcanic eruptions and earthquakes have caused additional problems for the capital city area.

As in other countries of the region, the major hydrologic hazards are floods and drought. El Salvador tends to be more prone to drought because it is located on the Pacific coast. It is rarely affected by hurricanes.

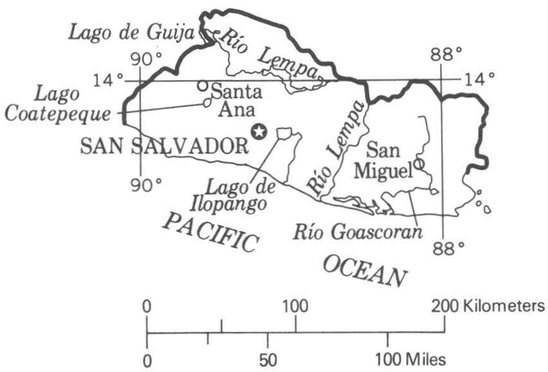


FIGURE 13.—Major surface-water features of El Salvador.

GEOTHERMAL ENERGY

El Salvador is the first Central American country to have constructed and operated geothermal electric powerplants. At the Ahuachapan field, three powerplants generate 95 MW and provide about 25 to 44 percent of the country's electricity from geothermal steam. Exploration began at Ahuachapan in the mid-1960's; by June 1975, the first single flash plant was in operation. The cost of three units at Ahuachapan was $96 million; however, 21 days after the inauguration of the third unit in November 1981, all three units had been paid for in oil savings. Berlin, another promising field about 90 km southeast of San Salvador (fig. 12), is undergoing continued exploration by the Comision Ejecutiva Hidroelectrica del Rio Lempa. The capacity of the field has been estimated at 110 MW and will probably be the site of El Salvador's fourth geothermal unit.

GUATEMALA

STATUS OF GEOLOGIC AND HYDROLOGIC INFORMATION AND PROGRAMS

Detailed geologic mapping in Guatemala is incomplete (Weyl, 1980, p. 324–325). The only comprehensive geologic map of the country is at a scale of 1:500,000 (Bonis and others, 1970). Other geologic map series in progress since 1966 include maps at scales of 1:50,000, 1:250,000 (Instituto Geografico Nacional de Guatemala, 1965–1975; Bundesanstalt fur Bodenforschung and Instituto Geografico Nacional de Guatemala, 1967–1971; unpublished theses, State University of New York at Binghamton).

The geologic terrane of Guatemala, unlike that of all other Central American countries except Belize, consists predominantly of sedimentary rocks; they cover about 60 percent of the country, mostly in the northern half, and extend into the Yucatan Peninsula of Mexico. An arcuate belt of young volcanic rocks covers about 20 percent of the country near the Pacific Ocean. Intrusive, metamorphic, and volcanic rocks of the Guatemala Massif form a mountainous highland north of the young volcanic rocks. Of special interest are ultramafic rocks that occur in the massif, occupy almost 5 percent of the country's area (fig. 14), and contain a world-class nickel deposit. Their location is controlled by the onshore extension of the Cayman trough (fig. 2). Guatemala is the only Central American country producing oil and gas.

MINERAL RESOURCES AND POSSIBILITIES

Guatemala produces or has produced antimony, chromite, copper, iron, lead, nickel, silver, tungsten, and zinc plus a wide variety of construction and industrial rocks and minerals. The world-class El Estor nickel mine (fig. 14), brought into production in 1977, was closed in 1980 (Mining Journal, 1983) pending a return to more favorable world economic conditions. The Oxec copper mine (Petersen and Zantop, 1980) is of regional importance in size and production. Lead and zinc deposits are known to occur in the older metamorphic rocks, and other small high-grade deposits are likely to exist. Lead and zinc deposits similar to those in the limestones of the Mississippi Valley in the United States should be looked for in the limestones. Ultramafic rocks should be explored for chromium, platinum-group elements, and copper. Submarine volcanic rocks, such as those at the Oxec mine (Petersen and Zantop, 1980), appear to have formed at a spreading center (Kesler, 1978) and should also be examined for similar deposits.

ENERGY RESOURCES AND POSSIBILITIES

The Rubelsanto and West Chinaja oilfields of Guatemala produced an average of 6,600 bbl/d of oil in 1981 and thus provided the country a very important source of foreign exchange. These fields occur on the southern flank of the Chapayal-Peten Basin (fig. 15), a geologic extension of the same basin that contains the prolific Reforma oil district of Mexico. Results of 1981 exploration in Guatemala were highlighted by the discovery of oil (700 bbl/d) at Well No. 1 Xan in the northwestern corner of the country. Exploration in this region will be continued by firms representing the United States and other countries. The changing character of producing formations southeast of the Mexican fields casts doubt on the possibility that fields of major size will be found in Guatemala, but additional small discoveries may be expected.

Coal has been reported in 11 of Guatemala's 22 departments; however, very little information on the character and extent of the coal beds is available. Records of analyses of a few coal samples are available, but a lack of information on sampling techniques used makes the analyses of questionable value. The general geology of Guatemala suggests that coal of three different geologic ages and three ranks (bituminous, subbituminous, and lignite) may be present. Figure 15 shows the locations of reported occurrences.

WATER RESOURCES

Guatemala, the most populous country in Central America, has a varied climate dominated by the Sierra Madre mountain range. Precipitation in the highlands averages from 500 to 2,000 mm/yr (20–79 in./yr). In the

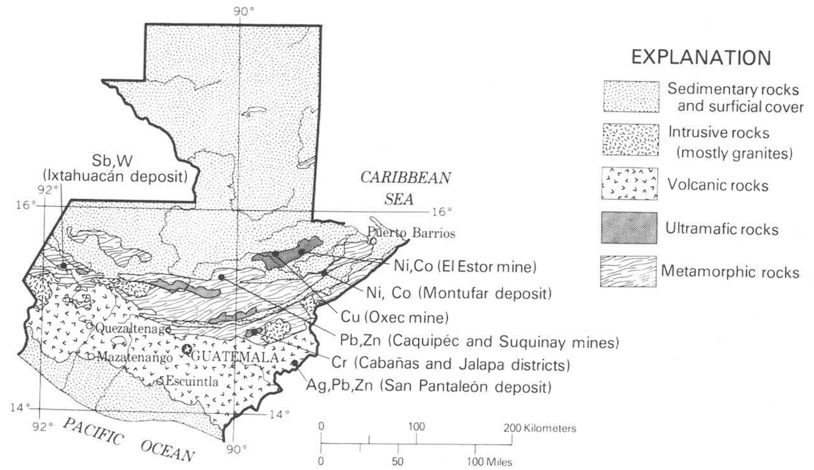
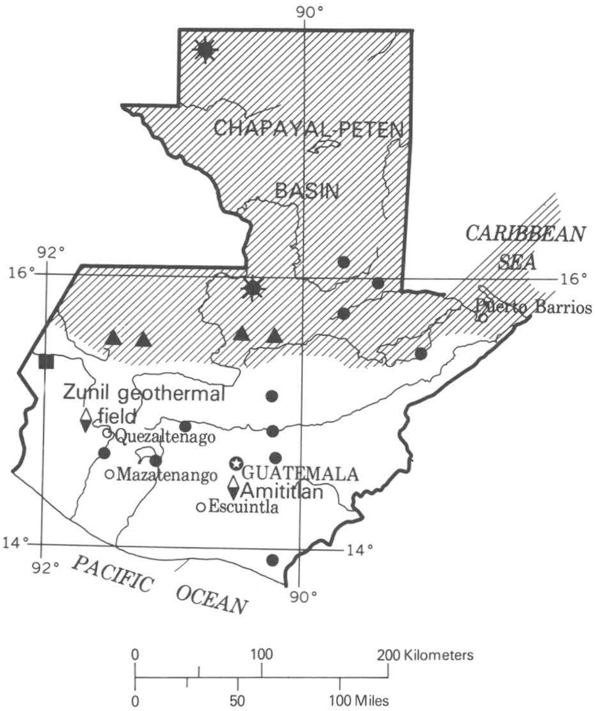


FIGURE 14. —Major geologic divisions and principal mineral deposits in Guatemala. Geology simplified from Case and Holcombe (1980). The metals contained in deposits are indicated by chemical symbols. Locality names are in parentheses.



EXPLANATION

Area of possible petroleum occurrence

Site of petroleum development

Reported occurrence of coal, by rank
- ● Lignite
- ▲ Subbituminous
- ■ Bituminous

Geothermal site under exploration or development

FIGURE 15.—Energy resource potential in Guatemala. The seaward boundary is defined by the 220-m isobath. The location of the Chapayal-Peten Basin, which is a regional feature of interest in petroleum exploration, is shown.

lowlands of the Peten karst region, annual precipitation averages from 2,000 to 6,000 mm (79–236 in.). Toward the Pacific coastal region, equally intense rain produces annual averages ranging from 2,000 to 5,000 (79–199 in.). The principal rivers in Guatemala include the Motagua, Salinas, and Rio de la Pasion (fig. 16). The abundant rainfall and geomorphologic characteristics define 33 distinct hydrologic basins.

The main hydrologic problems in Guatemala include a complex combination of drought and floods, contamination of surface and ground water, overdevelopment of aquifers in the valley of the city of Guatemala, severe erosion and sedimentation in coastal areas, and limited information for the management of the water resources. The country has 400 MW of hydropower now in use and a large untapped hydroelectric potential of about 4,300 MW.

Droughts are frequent in the Pacific watershed, whereas occasional severe floods (two since 1969) affect large areas in the Peten region and the southeastern part of the country. Surface water is heavily contaminated with sewage discharge (only 28 percent of all households in the country have sewer connections), which also affects ground-water supplies near urban areas. In the valley of the city of Guatemala, ground-water overdevelopment is affecting optimal yields of well fields.

Guatemala has prepared a master plan for the development of their water resources, and it has a limited number of trained professionals. The country needs additional financial and technical support to enhance its basic data-collection program.

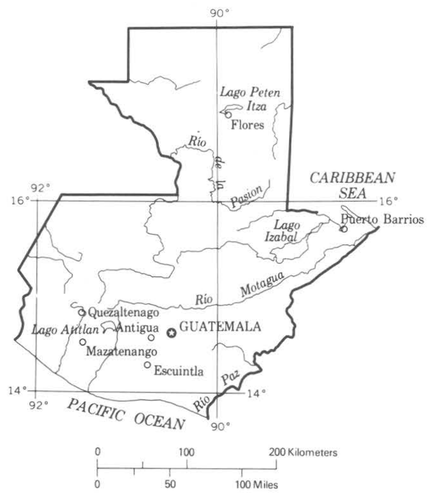


FIGURE 16.—Major surface-water features of Guatemala.

GEOLOGIC AND HYDROLOGIC HAZARDS

Numerous historical accounts of damaging earthquakes in Guatemala date from the time of the Spanish conquest. Antigua, the original capital of Guatemala, was extensively damaged 10 times before a great earthquake in 1773 prompted the capital's relocation to the city of Guatemala. Before 1976, the city of Guatemala had experienced devastating earthquakes in 1917–18, 1863, and 1862. In addition, great earthquakes having magnitudes of more than 8.0 on the Richter scale occurred less than 100 km south of the city of Guatemala in 1902 and 1942. The great earthquake of February 1976 occurred within the Motagua fault zone, the active boundary between the Caribbean and North America crustal plates (fig. 2). This earthquake claimed more than

22,700 lives, injured more than 76,000 people, and produced losses totaling about $1.1 billion.

Most of the 25 or so recently active Guatemalan volcanoes are clustered in three linear belts that parallel the Middle America thrust (fig. 2). Two of these volcanoes, Fuego and Santa Maria, have erupted in the last 4 yr. The explosive nature of these eruptions makes them extremely hazardous.

Flooding of the karstic depressions of northern Guatemala is a recurring serious problem for the city of Flores on Lake Peten Itza.

GEOTHERMAL ENERGY

At Zunil in western Guatemala (fig. 15), a small high-temperature geothermal reservoir has been confirmed by drilling, and a 15-MW geothermal unit is to be installed by 1986. In 1980, USGS scientists visited Guatemala to determine the geochemical character of the thermal waters at Zunil. Another geothermal field, Amititlan, is also of interest.

HONDURAS

STATUS OF GEOLOGIC AND HYDROLOGIC INFORMATION AND PROGRAMS

Geologic information necessary to evaluate the mineral resources of Honduras is inadequate. As of 1980, only 40 percent of the country had been topographically mapped at a scale of 1:50,000. A geologic map of the entire country at 1:500,000 scale is available (Elvir A., 1974).

In 1979, Honduras sought U.S. Reimbursable Development Program funding through the U.S. Embassy for feasibility studies on lignite and antimony mining projects. On June 2, 1980, the World Bank announced approval of a $3.65 million loan to provide technical assistance and training in petroleum exploration, pricing, and taxing. Honduras has also received assistance from the United Nations and Japan in projects involving gold occurrences in three specific areas (Vueltas de Rio, Zopotal, and Laguna Seca). The results have not yet been reported.

The Government of Honduras is currently seeking a grant from the Inter-American Development Bank to fund technical assistance for a national mineral-resource inventory. USGS has provided a summary work plan for such a project at the request of the bank.

The dominant geologic feature in Honduras is the Honduras Massif (fig. 17), a complex of metamorphic and igneous rocks occupying the northern part of the country. The massif covers about half the country and is geologically the oldest and tectonically the most stable terrane in Central America. Elsewhere, marine sedimentary rocks fill a central downfaulted block, and flat-lying

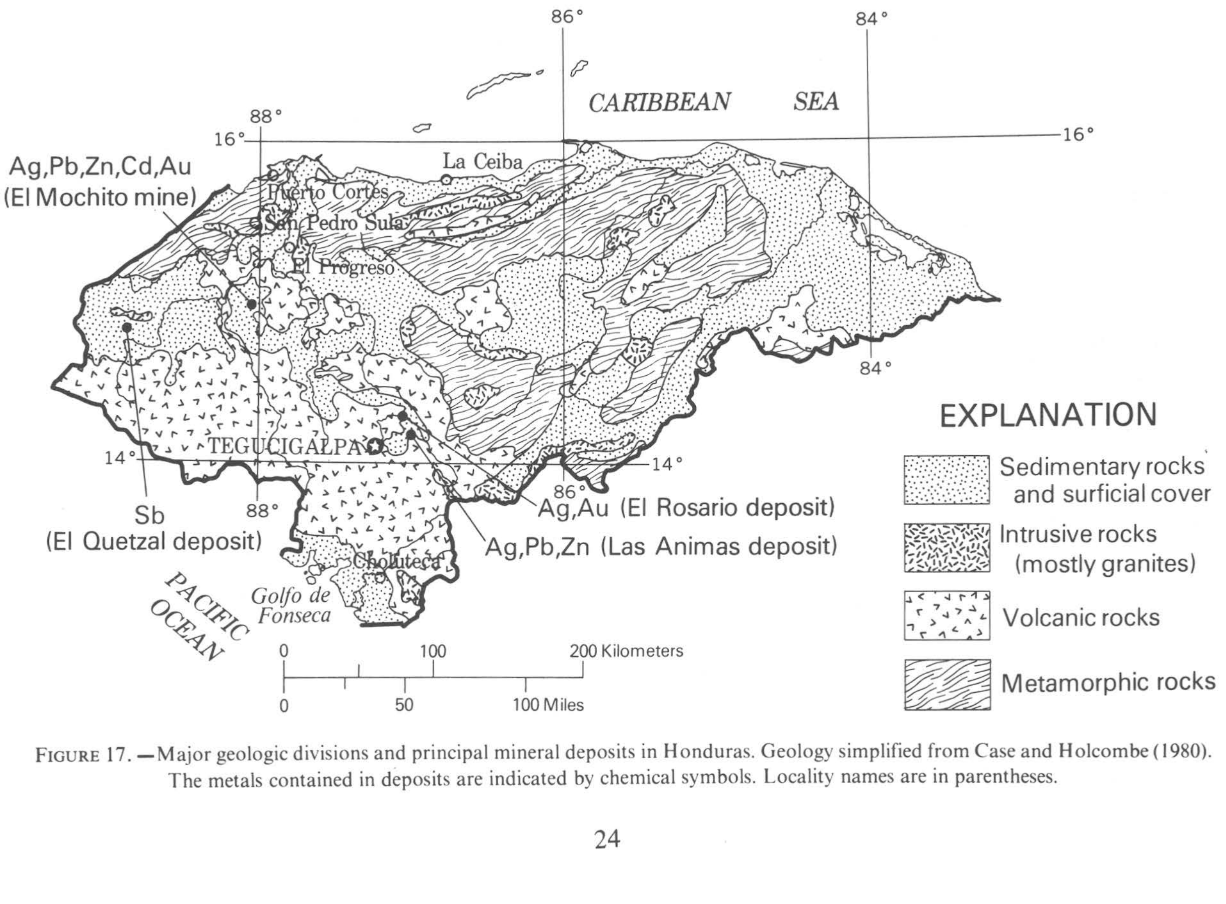


FIGURE 17.—Major geologic divisions and principal mineral deposits in Honduras. Geology simplified from Case and Holcombe (1980). The metals contained in deposits are indicated by chemical symbols. Locality names are in parentheses.

volcanic rocks of continental origin form a narrow plateau along the southern border, covering approximately 20 percent of the country.

MINERAL RESOURCES AND POSSIBILITIES

The mineral industry, based on the production of gold, silver, zinc, lead, copper, cadmium, antimony, gypsum, and salt, contributed almost 3 percent of the country's gross domestic product in 1981, the largest proportion contributed by the mining industry of any Central American country. Most of the production was silver, lead, and zinc from the El Mochito mine (fig. 17), the largest working mine in Central America in terms of total mining production and diversity of mineral products. Two additional deposits of regional importance containing silver, lead, and zinc ores are El Rosario and Las Animas (Guild, 1981, p. A39). Honduras led all Central American countries in silver production, producing 2,400,000 troy ounces in 1981 (Ensminger, 1983).

Antimony, copper, and mercury have been mined in the past (Roberts and Irving, 1957, p. 205), and manganese and iron deposits are known (Klemic, 1970; National Materials Advisory Board, 1981), but none of these are reported to be mined at present. Shale and sandstone northeast of Tegucigalpa accumulated in a geologic setting that may be similar to the setting of some Norilsk copper- and nickel-bearing deposits in other parts of the world. These rocks should be examined futher to determine the likelihood of copper and nickel deposits occurring.

ENERGY RESOURCES AND POSSIBILITIES

Oil and gas have been sought in Honduras, both onshore and offshore, not only on the coastal plain and in the Caribbean (fig. 18) but also in small intermontane basins. Thusfar, no discoveries have been made, but oil seeps have been reported. The most favorable area is offshore in the Caribbean, where thick layers of carbonate and clastic rocks are present on the Nicaragua Rise. Drilling, to depths of 3,000 to 4,500 m (10,000–15,000 ft), has not revealed the presence of source rocks or of temperatures that would lead to hydrocarbon development. Nevertheless, interest is still being shown by companies, including one U.S. firm holding exploration permits.

Coal has been reported at 10 different localities in Honduras (fig. 18). Of these, six are in relatively old rocks. One of these coals may be of bituminous rank, and four are probably of subbituminous rank. Four that are in relatively young rocks are lignite. Some data available on the older coals indicate that beds more than 1 m (3.3 ft) thick are present in several localities; one bed ranging in thickness from 2 to 5 m (6.4–16 ft) has been reported. Most of these coal beds have high ash content but low to medium sulfur content. From the brief descriptions, it appears that much of the ash may be in interbeds or partings of shale within the beds of the coal sequence. This deleterious material can be removed readily by gravity separation.

Lignite is reported at four localities, but information on the beds is available for only one of them. The lignite there is 1.8 m (5.7 ft) thick but has a high ash content.

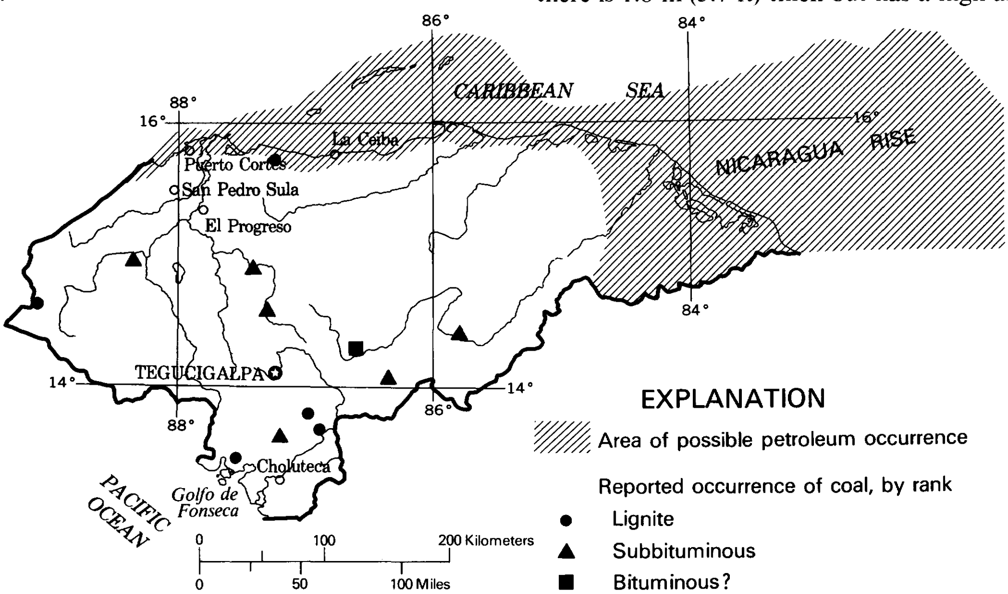


FIGURE 18.—Energy resource potential in Honduras. The seaward boundary is defined by the 200-m isobath. The location of the Nicaragua Rise, which is a regional geologic feature of interest in petroleum exploration, is shown.

WATER RESOURCES

Honduras, the second largest country in Central America, has a rugged topography (80 percent mountains) and a moderate temperate climate. Annual average precipitation ranges from 1,500 mm (60 in.) in the interior valley to as much as 3,000 mm (118 in.) in the north-central mountains. Most of the rain occurs from April to October and results in frequent floods and droughts. The country is also affected by frequent hurricanes from the Caribbean (five since 1965). The principal rivers in the country include the Patuca and the Ulua (flowing to the Caribbean) and the Choluteca (flowing to the Pacific) (fig. 19).

Hydroelectric generation provides about 61 percent of the power used in Honduras, but the country's potential (about 4,000 MW) is largely untapped. Geothermal energy potential has also been identified in Honduras.

The ground-water resources of Honduras are limited by the low porosity and permeability of the aquifers formed by volcanic rocks. The most productive aquifers occur in the alluvial valleys of the Choluteca and Guayape Rivers, where yields from wells can be as high as 60 L/s (900 gal/min). Ground-water development is significant along the northern area for banana plantations and in the Tegucigalpa area for the water supply.

The principal hydrologic problems in Honduras are frequent floods and droughts, contamination of surface and ground water, and limited information for the development and management of water resources. A National Ground Water Service was recently funded to prepare a national ground-water development program.

Technical support is needed to provide additional training, and financial support to acquire equipment and facilities is essential.

GEOLOGIC AND HYDROLOGIC HAZARDS

The threat of damaging earthquakes and volcanic eruptions is not as great in Honduras as it is in most other Central American countries. Earthquakes do, however, occur and tend to be concentrated along the northern seacoast. Caribbean hurricanes have caused severe flooding in Honduras. Hurricane Fifi caused major damage and loss of life in 1974. The southern and western portions of the country are subject to drought whenever there is a delay in the onset of the rainy season.

GEOTHERMAL ENERGY

In 1977, a geothermal exploration program, now in abeyance, was focused on the Pavana area near Choluteca

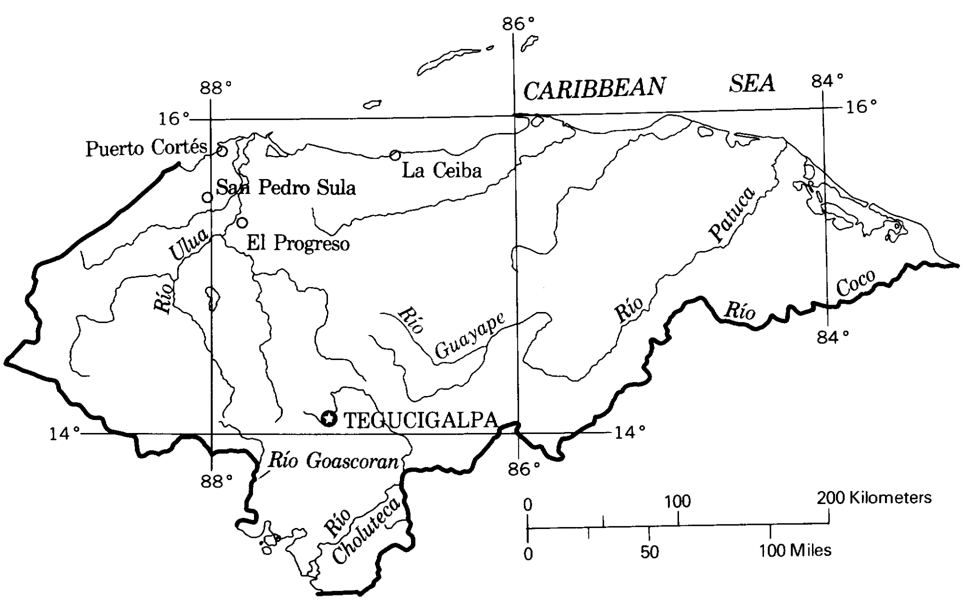


FIGURE 19.—Major surface-water features of Honduras.

ing in the southernmost part of the country and on the San Ignacio area northwest of Tegucigalpa.

NICARAGUA

STATUS OF GEOLOGIC AND HYDROLOGIC INFORMATON AND PROGRAMS

A preliminary geologic map of Nicaragua at a scale of 1:1,000,000 (Martinez and Kuang, 1973) has been published in addition to other geologic maps at scales of 1:250,000 (Weyl, 1980, p. 327).

More than half the country is covered by young flat-lying volcanic rocks that overlie the older metamorphic and crystalline basement rocks exposed in the northern part of Nicaragua (fig. 20) and in the Honduras Massif. A chain of volcanoes, many of which have been active in historic time, parallels the Pacific coast in the southwestern part of the country. The Caribbean coastal plain is made up of a thick sequence of sedimentary rocks consisting of sandstone, shale, and limestone of both continental and marine origin.

MINERAL RESOURCES AND POSSIBILITIES

Minerals produced in Nicaragua in 1981 included gold, silver, and the industrial rocks and materials (gypsum, anhydrite, salt, sand, lime, and cement). Nicaragua's output of 70,000 troy ounces of gold in 1981 was the largest of any Central American country (table 1). World-class mines producing gold are Sententrion (formerly El Limon), Siuna, and Vesubio (fig. 20, table 2). Small amounts of copper, lead, and zinc were produced prior to 1972. Occurrences of antimony, tungsten, molybdenum, and phosphate have also been reported (Levy, 1970; Cathcart, 1977; Weyl, 1980).

ENERGY RESOURCES AND POSSIBILITIES

Exploration for oil and gas has been conducted in both the Caribbean and the Pacific areas of Nicaragua; although a deep test drilled offshore in the Caribbean by the Shell Oil Company was reported to have found oil at about 3,600 m (11,800 ft), offsetting holes have not been productive. The best aspects for oil and gas are in the thick carbonate and clastic rocks of the Nicaragua Rise (fig. 21). Several tests drilled in the narrow basin along the Pacific coast have been unsuccessful.

Exploration has been halted by the unsettled political situation in Nicaragua. No activity has been reported since 1980, although 52,633 km^2 in concessions were still held at the end of 1981.

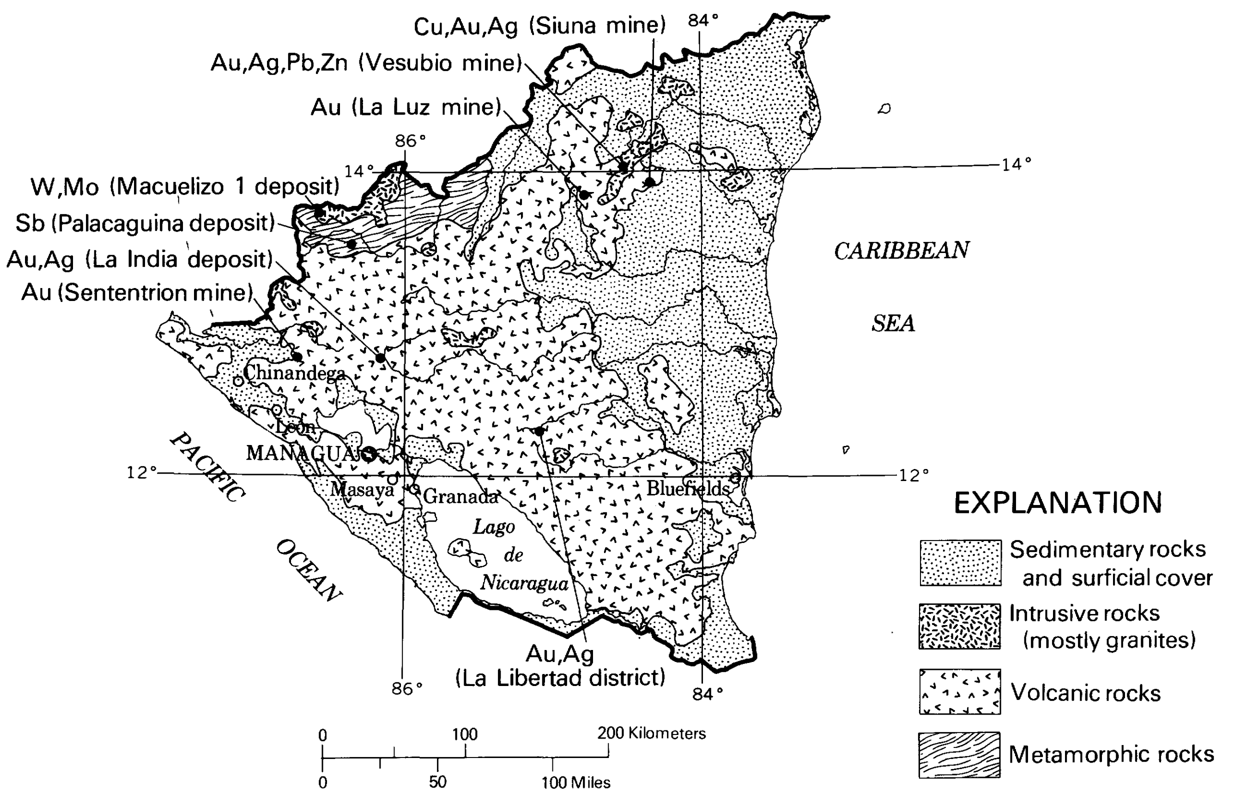


FIGURE 20.—Major geologic divisions and principal mineral deposits in Nicaragua. Geology simplified from Case and Holcombe (1980). The metals contained in deposits are indicated by chemical symbols. Locality names are in parentheses.

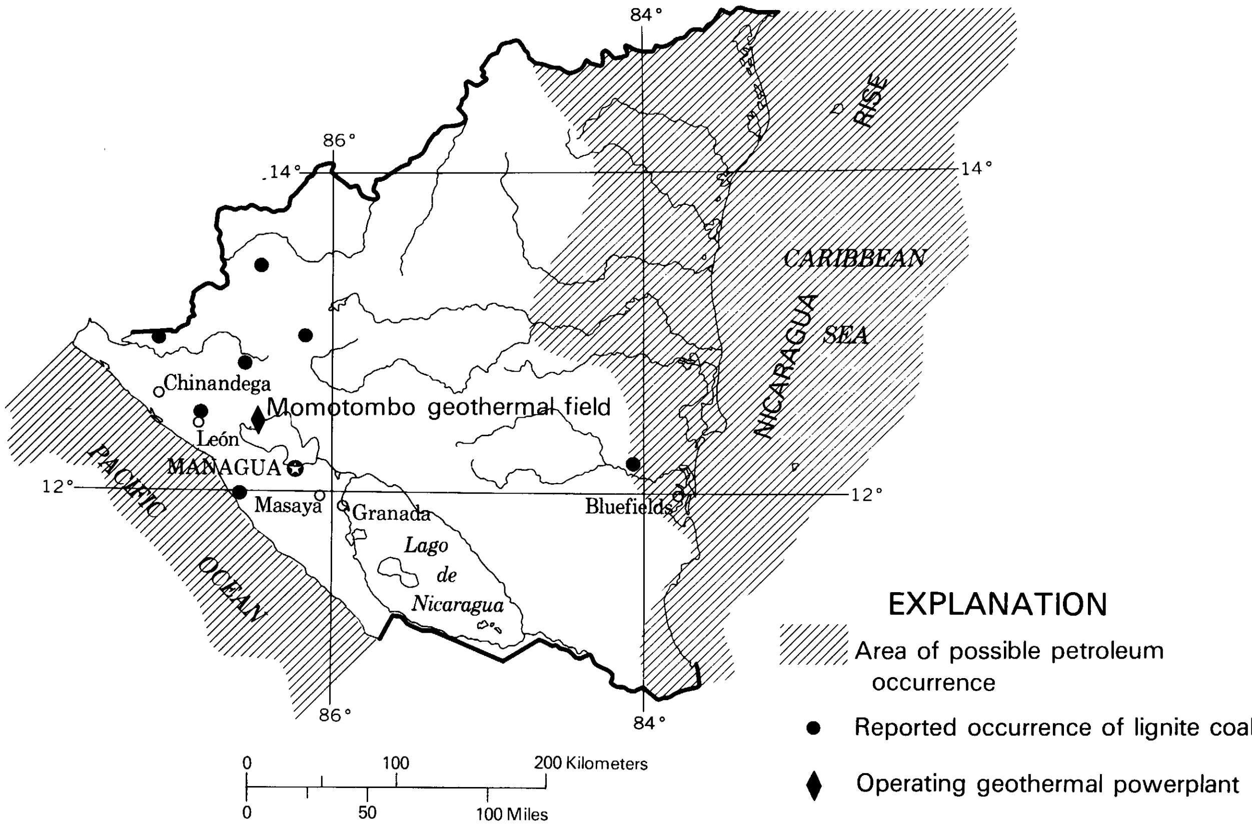


FIGURE 21.—Energy resource potential in Nicaragua. The seaward boundary is defined by the 200-m isobath. The location of the Nicaragua Rise, which is a regional geologic feature of interest in petroleum exploration, is shown.

Nicaragua is said to have lignite in seven localities (fig. 21), but no data on the occurrences have been reported.

WATER RESOURCES

Nicaragua, the largest country in Central America, has abundant surface- and ground-water resources. Precipitation ranges from as little as 400 mm/yr (16 in./yr) in the western highlands to as much as 6,300 mm/yr (250 in./yr) in the wet, humid Caribbean plain. In most of the country, rainfall ranges from 2,400 to 4,000 mm/yr (95–157 in./yr). The principal rivers in Nicaragua include the Rio Grande de Matagalpa, the Coco, the Prinzapolka, and the San Juan, all flowing to the Caribbean (fig. 22); all are partially navigable. Nearly 90 percent of the runoff is to the Caribbean. Floods are not frequent in Nicaragua, but the Caribbean coast is vulnerable to hurricanes. Hydroelectric and geothermal energy production is significant, and there is additional undeveloped potential. Nicaragua also has ample water supplies from Lakes Managua and Nicaragua.

Ground water meets most of Nicaragua's industrial and domestic needs. Water use in 1972 was about 40 million cubic meters, 75 percent of which was for industrial use. Projected use for 1982 was about 90 million cubic meters. Overdevelopment of the country's aquifers is occurring in the major metropolitan areas of Managua-Granada, Leon, and Chinandega. Seawater intrusion has been detected in areas along the Pacific shore. Contamination of surface- and ground-water supplies by sewage discharge has been identified as one of the most significant water-resources problems (only about 40 percent of all households have sewer connections).

A significant data base of the ground-water resources of the country has been developed and detailed investigations made in several areas. Technical support is needed to train additional staff in modern techniques and procedures for water-resources data collection, appraisal, and management.

GEOLOGIC AND HYDROLOGIC HAZARDS

Earthquakes are frequent in Nicaragua. Most originate along the Middle America thrust (fig. 2), which results from the northeasterly movement of the Cocos plate beneath the Caribbean plate. Epicenters of earthquakes are often located at the intersections of the topographic depression that parallels the trend of Central American volcanoes and the depressions that run transverse to the coastline. Such is the case at Managua, capital city of Nicaragua, which has been repeatedly destroyed by earthquakes. Most recently, in December 1972, a severe magnitude 6.2 earthquake killed over 11,000 people, caused more than half a billion dollars in property damage, and destroyed 75 percent of Managua's housing. A long-time seismically quiet zone has recently been identified off the Pacific coast of Nicaragua, southwest of Managua. It has been postulated that an earthquake of magnitude greater than 7 will occur in this area in the next several decades.

In addition to geologic hazards related to earthquakes, Nicaragua has had a long history of active volcanism. At least eight volcanoes have erupted in the last century. Two of the three most explosive and potentially devastating volcanoes in Nicaragua (Apoyeque and Apoyo) are within 35 km of the center of Managua. Clearly, volcanic risk needs to be carefully evaluated and taken into account in urban planning for Managua.

Although earthquakes and volcanoes are the most prominent natural hazards, Nicaragua is also prone to drought and occasionally to flash flooding. The Caribbean coast is subject to hurricanes, and the Pacific coast often suffers drought during the dry season.

GEOTHERMAL ENERGY

This year, Nicaragua joined El Salvador as a geothermal energy producer. A 35-MW plant, which began operation in August near Momotombo Volcano, provides 12 percent of Nicaragua's energy needs (fig. 21). Italy is the primary financial backer of this project.

PANAMA

STATUS OF GEOLOGIC AND HYDROLOGIC INFORMATION AND PROGRAMS

Semidetailed geologic mapping has been carried out in parts of Panama as part of the United Nations Development Program (Administracion de Recursos Minerales, 1969–1971), in the Panama Canal Zone and vicinity by the USGS (Stewart and Woodring, 1980), and for the entire country (Larocque and others, 1972; Direccion General de Recursos Minerales, 1976). Modern detailed geologic maps needed to identify and assess resources are virtually nonexistent, and the geologic map of Panama (fig. 23) is highly generalized.

Nearly 70 percent of the country consists of volcanic rocks. The arcuate belt of folded volcanic rocks in the east is submarine in origin. Volcanic rocks of continental origin along with intrusive rocks occupy a broad platform in the western part of Panama. A thick section of marine sedimentary rocks that may be favorable for

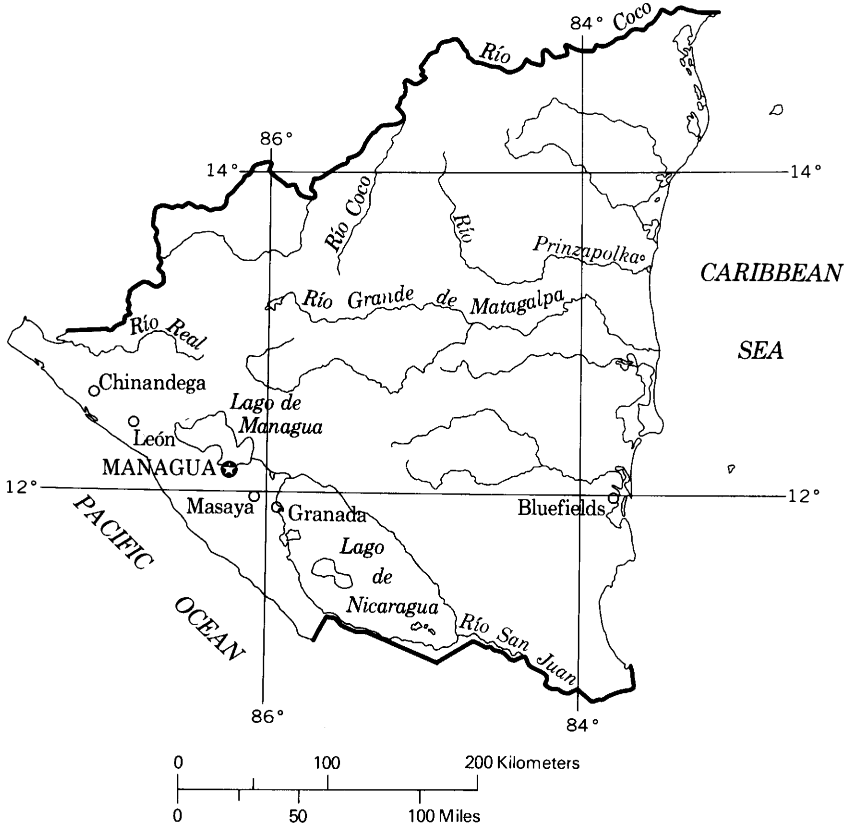


FIGURE 22.—Major surface-water features of Nicaragua.

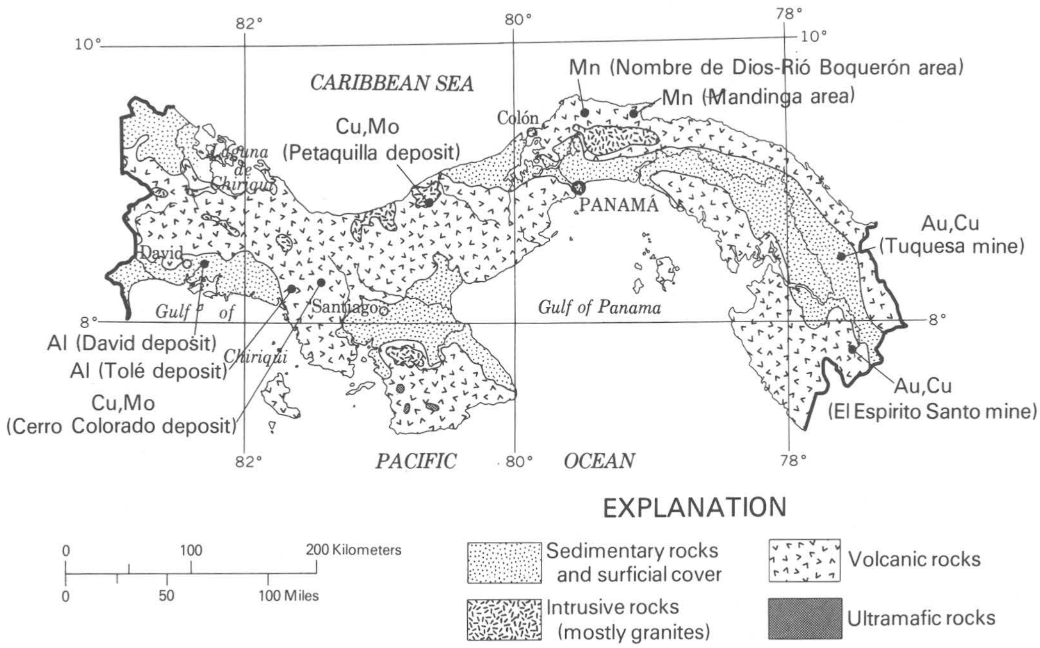


FIGURE 23.—Major geologic divisions and principal mineral deposits in Panama. Geology simplified from Case and Holcombe (1980). The metals contained in deposits are indicated by chemical symbols. Locality names are in parentheses.

hydrocarbons is present at the eastern half of the isthmus. Small areas of ultramafic rocks are present on the peninsula southwest of the city of Panama (Case and Holcombe, 1980).

MINERAL RESOURCES AND POSSIBILITIES

Mineral-industry production in 1981 was confined almost entirely to limestone and clay (Ensminger, 1983). The country has extensive resources of copper and molybdenum at two deposits (Cerro Colorado and Petaquilla) (fig. 23) (Prokop, 1975, p. 42), but low world copper prices and the high cost of energy have inhibited development of these resources (Mining Journal, 1983). Aluminum resources are reported in the provinces of Chiriqui and Veragas (Patterson, 1967, p. 40). Alluvial gold has been produced in the past and, together with titanium, platinum, and rare-earth-bearing sands, might well be explored for in nearshore submerged deposits. Gold has been produced in many places in the past; before the mid-19th century, the El Espirito Santo mine was one of the largest gold producers in the western hemisphere. Rocks and a geologic setting similar to those that host the Pueblo Viejo mine in the Dominican Republic (one of the largest gold mines in the western hemisphere) (Kesler, 1978) are reported to exist here (Stewart, 1975) and should be examined for the presence of disseminated gold deposits. Manganese has been produced in the past, and areas of submarine volcanic rocks that may have the same type of geologic setting that hosts the large manganese deposits of Cuba should be examined for additional deposits. Phosphate has been reported (Cathcart, 1977). Additional copper and molybdenum deposits could probably be located by using new exploration techniques.

ENERGY RESOURCES AND POSSIBILITIES

Oil and gas possibilities in Panama are limited because of the predominance of volcanic rocks, which generally do not include good source or reservoir rocks. Reef limestones may offer prospective targets, and the relatively high heat flow on the Pacific side of the isthmus favors the formation of petroleum at reasonable drilling depths. Considerable drilling done in intermontane basins in southeastern Panama suggests that shows of oil may have been encountered. The offshore continental shelf is narrow (fig. 24) on the Caribbean coast but rather broad on the Pacific side. Recent petroleum leasing in the Gulf of Chiriqui and the Gulf of Panama indicates that industry is interested in that area.

Coal beds were reported in northwestern Panama more than a century ago by Evans (1861). He regarded the coal beds as geologically and geographically favorable for development. These beds crop out on the mainland and islands surrounding Laguna de Chiriqui, which forms the largest and safest harbor on the Caribbean coast of Central America. Evans measured coal beds

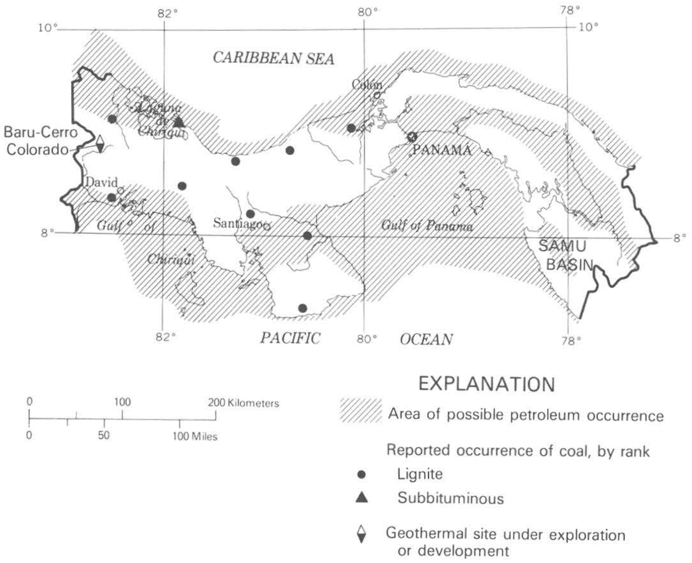


FIGURE 24.—Energy resource potential in Panama. The seaward boundary is defined by the 200-m isobath.

from 0.6 m (2 ft) to as much as 1.7 m (6 ft) thick at a number of localities. He reported that the coal was low in ash and sulfur, but the sampling and analytical procedures on which his determination was based are not known. The coal may be of subbituminous rank, similar to the coal across the western border in Costa Rica. No systematic mapping, exploration, or appraisal of these coal beds has been undertaken.

The coal in the Laguna de Chiriqui area might be a significant resource and should be explored. A proposal for investigating this coal is under consideration by USAID. Lignite has been reported at nine localities in Panama (fig. 24), but information on thickness and quality of the beds is lacking.

WATER RESOURCES

Panama has a tropical humid climate; annual precipitation ranges from 1,500 to 5,500 mm (59–198 in.). Two distinct physiographic zones occur: the Caribbean watershed, which is affected by trade winds and tropical disturbances, and the Pacific shores, which include the Azuero Peninsula (to the south) and the Darien area (to the southeast). Precipitation varies throughout the year and affects runoff significantly. Extreme droughts are not frequent but can occur in the Azuero area. The principal rivers in the Caribbean watershed (30 percent of the country area) include the Changuinola and the Cocle del Norte (fig. 25). In the Pacific area, the Chiriqui, the Santa Maria, and the Chepo are the main rivers.

Surface water provides most of Panama's urban water needs. Flooding occurs frequently in response to tropical disturbances and to hurricanes in the Caribbean area.

Ground-water development in Panama has been limited to small wells for rural areas and industrial facilities. A generalized assessment of the ground-water resources of the country is not available. Preliminary investigations indicate that aquifers can yield as much as 500 gal/min in selected areas.

The principal hydrologic problems in Panama include lack of water-resources information, contamination of surface and ground water, and erosion and sedimentation. The lack of sewer facilities in about 30 percent of all households contributes to contamination of surface and ground water.

Technical and financial assistance is needed in the form of training personnel, acquiring equipment, and supporting facilities.

GEOLOGIC AND HYDROLOGIC HAZARDS

The junction of several major crustal plates is located in Panama. Because earthquakes commonly occur where plates collide or slide past one another, Panama has experienced numerous damaging earthquakes. Earthquake hazards are a major concern not only to Panama but also to the United States because they threaten power facilities in the Canal Zone and the integrity and stability of the canal itself. Large earthquakes have the potential to trigger massive landslides along the canal banks (many of which are composed of weak clay) and to damage lock and dam facilities.

The major hydrologic hazards in Panama are flash floods that affect flood-plain communities.

GEOTHERMAL ENERGY

Geothermal resources are believed to exist in Panama, where extensive volcanic deposits and high heat flow create favorable conditions. Preliminary feasibility studies, like those done at Baru-Cerro Colorado (fig. 24), are supported by the Inter-American Development Bank and are currently in progress.

CONCLUSIONS AND RECOMMENDATIONS

Effective long-range economic growth and development in Central America needs to include development of indigenous mineral, energy, and water resources for

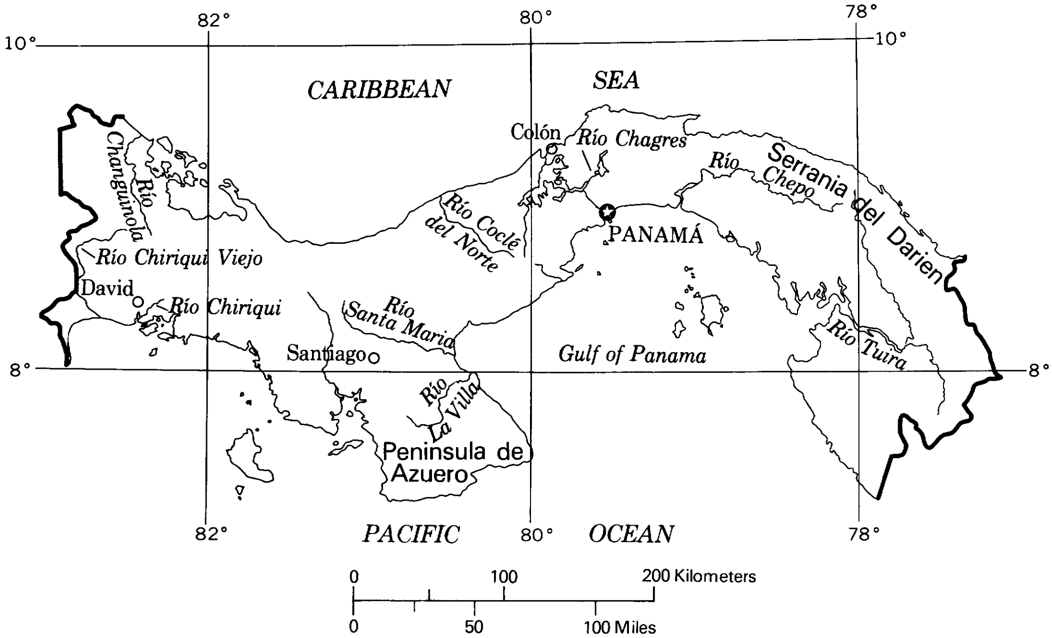


FIGURE 25.—Major surface-water features of Panama.

domestic, agricultural, industrial, and trade purposes. The results of this review indicate that (1) excellent conditions exist for discovery and development of additional mineral and energy resources, (2) there is a history of natural disasters and a continuing threat from geologic and hydrologic hazards, and (3) substantial benefits will result from a rational development of water resources.

Scientific and technical assistance to Central American countries is essential for the development of their natural resources. The elements of such assistance should include (1) preparation of a systematic, detailed analysis of the status of geologic and hydrologic information, (2) a cooperative review of the need for additional earth-science activities, and (3) the definition of specific activities needed for mineral-, energy-, and water-resources evaluation and geologic and hydrologic hazard mitigation. All activities should be designed to train national scientists and to strengthen local institutions.

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APPENDIX 1.—U.S. GEOLOGICAL SURVEY ACTIVITIES IN CENTRAL AMERICA AND BIBLIOGRAPHY OF REPORTS RESULTING FROM U.S. GEOLOGICAL SURVEY SCIENTIFIC AND TECHNICAL COOPERATION WITH CENTRAL AMERICAN COUNTRIES, 1940-1983

The U.S. Geological Survey has had active scientific programs in many Caribbean Basin and South American countries. USGS has provided technical assistance and (or) training in resource investigation and hazard mitigation, with excellent results, to Argentina, Bolivia, Brazil, Chile, Colombia, Costa Rica, Cuba, Ecuador, El Salvador, Guatemala, Guyana, Haiti, Nicaragua, Panama, Paraguay, Peru, Santo Domingo, St. Vincent, and Venezuela.

Initial studies in Central America include a summary report on strategic and other significant minerals in Central America (Roberts and Irving, 1942) done under the auspices of the Interdepartmental Committee on Scientific and Cultural Cooperation (ICSCC) of the Department of State. Roberts also investigated the manganese deposits in Costa Rica (Roberts, 1944) and manganese and antimony deposits in Honduras. From 1943 to May 1945, several USGS geologists investigated mineral deposits in Guatemala, Honduras, El Salvador, Nicaragua, and Panama (Roberts and Irving, 1957). Water resources studies were made in El Salvador from 1943 to 1944, in Nicaragua in 1943 and 1949, in Panama in 1949, and again in El Salvador in 1947. The reports describing these studies are listed in this appendix.

The only USGS study directly related to petroleum exploration in Central America was made in 1946 by W.P. Woodring, who collected and described fossils in Tertiary formations in Panama to determine their possible use as a tool in the search for petroleum. The project was sponsored by the ICSCC in cooperation with the Government of Panama (Woodring, 1957; Woodring and Thompson, 1949).

A 5-week study of Guatemalan mineral resources was made by R.L. Miller in 1961 at the request of the Government of Guatemala and sponsored by the International Cooperation Agency. Miller advised the Direccion de Minas y Hidrocarburos and the Direccion General de Cartografia on the potential for industrial minerals and coal in an effort to widen Guatemala's economic base.

In 1963, Irazu Volcano began a catastrophic eruption that dumped ash on the surrounding countryside over a 2-yr period. The resulting crop damage, landslides, mudflows, and accelerated erosion caused widespread economic hardship. Early in 1964, the USGS conducted an aerial infrared heat sensing survey of the volcano, sponsored by USAID in cooperation with the University of Michigan and the Costa Rican Instituto Geografico (Gawarecki and others, 1980). Later that same year, USGS began a project to help the Government of Costa Rica mitigate the effects of future eruptions. The work, done in cooperation with the Direccion de Geologia, Minas y Petroleo, included installation of permanent seismographs to monitor volcanic activity, water-supply study, and geologic mapping. Detailed slope-stability maps and reports and geologic maps were prepared. Recommendations for protection from future mud and debris flows and floods and the training of counterpart scientists ensued.

In the 1960's, Miller was instrumental in initiating and stimulating the development of a School of Central American Geology at the University of Costa Rica to fill an almost complete void of native-born geologists. Robert Wallace assisted in planning the curriculum. Financial support to the fledgling school was provided by USAID. The school has flourished, and its graduates are now employed in many places in Central America. They are available to work with technical specialists from the USGS and from other foreign countries to further develop their skills in exploring for and evaluating resources in their own countries.

In 1968, D.E. White, in collaboration with a United Nations team and the Comision Ejecutive Hidroelectrica del Lempa, investigated the geothermal resources of El Salvador. The work also entailed establishing a geochemical laboratory. In the same year, White visited Nicaragua as part of a USAID project to work with the Servicio Geologico de Nicaragua in evaluating proposals for a feasibility study on producing electricity geothermally. These cooperative investigations led to the completion of the El Salvador commercial geothermal electric plant, the first in Central America, and to further exploration and drilling of a favorable site in Nicaragua.

After the 1972 earthquake that destroyed the heart of Managua, Nicaragua, and an earlier earthquake in the suburbs of that city in 1968, USGS sent a team of earthquake specialists to study earthquake phenomena and to advise on geologic conditions that would have to be considered in planning reconstruction to minimize the damage from future earthquakes. A subsequent project established and equipped a Center for Earthquake Hazard Reduction and trained a staff for the center. Technical assistance to this endeavor continued into 1977.

In 1976, USGS made geologic and engineering studies of the February 4, 1976, earthquake in Guatemala, which caused extensive damage to buildings over a wide area owing to faulting, ground failure, and landslides. The effort was directed toward lessening the impact of inevitable future earthquakes.

Currently, USGS is involved in a coal-resources program in Costa Rica sponsored by USAID, in earthquake-monitoring programs in Panama, Guatemala, and El Salvador, also sponsored by USAID, and in consultations relative to other possible projects in Central America.

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APPENDIX 2.—EARTH-SCIENCE AGENCIES IN CENTRAL AMERICAN COUNTRIES

BELIZE

Ministry of Natural Resources
Belmopan

Ministry of Energy and Communications
Belmopan

National Water and Sewer Authority

National Meteorological Service
Ministry of Energy and Communications
Belize International Airport
Belize City

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Corporacion Costarricense de Desarrollo (CODESA)
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Instituto Geografico Nacional
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Instituto Costarricense de Electricidad
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Servicio Nacional de Aguas Subterraneas (SENAS)
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San Jose

Direccion de Geologia, Minas y Petroleo
Ministerio de Economia e Industria
Apartado 10216
San Jose

Refinadora Costarricense de Petroleo
Direccion de Recursos Carboniferos
P.O. Box 4351
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EL SALVADOR

Centro de Investigaciones Geotecnicas
Ministerio de Obras Publicas
Avenida Peralta, final, costado Oriente Talleres El Coro
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Comision Ejecutiva Hidroelectrica del Rio Lempa
9 Calla Poniente, #950
Centro de Gobierno
San Salvador

Comision Nacional del Petroleo
Ministerio de Economia
3a Calle Poniente 1225
San Salvador

Instituto Geografico Nacional "Ingeniero Pablo Arnoldo Guzman"
Ministerio de Obras Publicas
Avenida Juan Bertis No. 79
San Salvador

Ministerio de Obras Publicas
Palacio Nacional
San Salvador

Direccion General de Riego y Dranaje
Ministerio de Agricultura y Ganaderia
Nueva San Salvador

Servicio Hidrologico
Direccion General de Recursos Naturales Renovables
Canton El Matasano
Soyapango

Servicio Meteorologico Nacional
Ministerio de Agricultura y Ganaderia
Nueva San Salvador

Ministerio de Agricultura y Ganaderia
Boulevard Los Heroes y 21 Calle Poniente
San Salvador

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Ministeria de Energia y Mineria
Diagonal 17 entre 20 y 30 Calles, Zona 11
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Observatorio Nacional
La Aurora, Zona 13
Guatemala City

Instituto Geografico Nacional
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HONDURAS

Exploracion Geotermica
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Instituto de Recursos Hidraulicos y Electrificacion (IRHE)
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