GRAVITY ANOMALIES OF COSTA RICA AND THEIR RELATIONS TO CRUSTAL STRUCTURE AND MINERALIZATION

By

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ABSTRACT

Complete Bouguer and isostatic anomaly maps compiled for Costa Rica provide new insights into the crustal structure and mineralization. Terrain corrections were approximated from the station to a radial distance of 167 km by computer using a 3-minute digital elevation model of Costa Rica and surrounding areas. Isostatic corrections, based on Airy-Heiskanen compensation, were also calculated from 0 to 167 km using the 3-minute elevation model and from 167 km to 180 degrees using combined topographic and isostatic reduction maps.

Costa Rica can be divided into four main terranes based on gravity data: a Pacific coastal region, a Pacific inland area, a central region, and a Caribbean coastal region. Negative gravity anomalies along the Pacific coastal margin correlate with an offshore sedimentary basin, and large positive anomalies correlate with mafic and ultramafic igneous rocks on the Santa Elena, Nicoya, and Osa Peninsulas, and at Puerto Quepos. Pacific inland anomalies are separated from the Pacific coastal region by a steep gravity gradient, and over the Coast Ranges a major gravity low overlies a thick section of low-density sedimentary rocks. In the central region, a major gravity low occurs over a thick low-density Quaternary volcanic complex in the Cordillera Central, north of San Jose. A prominent feature of the Caribbean coastal region is an interrupted gravity low over the Limon Basin that reflects a thickening of low-density sedimentary rocks.

A conspicuous gravity lineament, trending northeast separates northern and southern Costa Rica. The lineament is defined by the termination of several major gravity anomalies including those over the Coast Ranges, Cordillera Central, Puerto Quepos, and Limon Basin. In addition, the lineament correlates with other geological and geophysical data including: northeast-trending faults, the southern limit of large Quaternary volcanoes, the segmentation of the Middle America volcanic belt, and a seismicity gap. This lineament may be the expression of a previously unrecognized major northeast-trending fracture zone in central Costa Rica. An important economic implication of the gravity lineament is a correlation with the termination of gold and porphyry copper deposits in Costa Rica.

INTRODUCTION

Complete Bouguer (fig. 1) and isostatic (not shown) anomaly maps of Costa Rica, the first such maps in Central America, provide new insights into crustal structure and mineralization. Previous gravity anomaly maps of Costa Rica, based on very sparse gravity data, were only reduced to free-air and simple Bouguer anomalies. Monges Caldera (1961) compiled a simple Bouguer anomaly map of Costa Rica at a scale of 1:1,000,000. Bowin (1976) described the gravity field and plate tectonics of the Caribbean region and included free-air and simple Bouguer gravity anomaly maps of the region. In Costa Rica, Bowin's maps were based on the data coverage of Monges Caldera's map which included only about 160 gravity stations.

About 11,200 observed gravity values were used to compile the gravity maps of Costa Rica, of which about 8,700 stations are within the border of figure 1 (National Geophysical Data Center, National Oceanic and Atmospheric Administration, Mail Code E/Gcx2, 325 Broadway, Boulder, CO 80303 USA, written commun., 1985; Ponce, 1986). Gravity stations were collected by many groups including: Hawaii Institute of Geophysics, Instituto Costarricense Electricidad, Instituto Geografico Nacional, Lamont-Doherty Geological Observatory, Oregon State University, Refinadora Costarricense de Petroleo, U.S. Geological Survey, Woods Hole Oceanographic Institution, private industry, and others. In addition, more than 7,300 proprietary gravity stations were used to compile the gravity maps. Locations of proprietary data are not shown on figure 1.

GRAVITY METHODS

Standard gravity corrections were made on

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all the data. Data were reduced using the Geodetic Reference System of 1967 (International Union of Geodesy and Geophysics, 1971) and referenced to the International Gravity Standardization Net 1971 observed gravity datum (Morelli, 1974). Terrain corrections, which remove the gravity effect of the topography surrounding a station, were approximated by computer using a 3-minute average digital elevation model of Costa Rica (J. M. Glen, D. A. Ponce, and T. V. Bare, written commun., 1986). Terrain corrections were calculated from the station to a radial distance of 166.7 km. Finally, isostatic corrections, based on an Airy-Heiskanen model with local compensation (Heiskanen and Moritz, 1967), were calculated from 0 to 166.7 km using the 3-minute elevation model (Simpson, Jachens, and Blakely, 1983). A combined isostatic and topographic correction for regions beyond 166.7 km were derived from published maps of

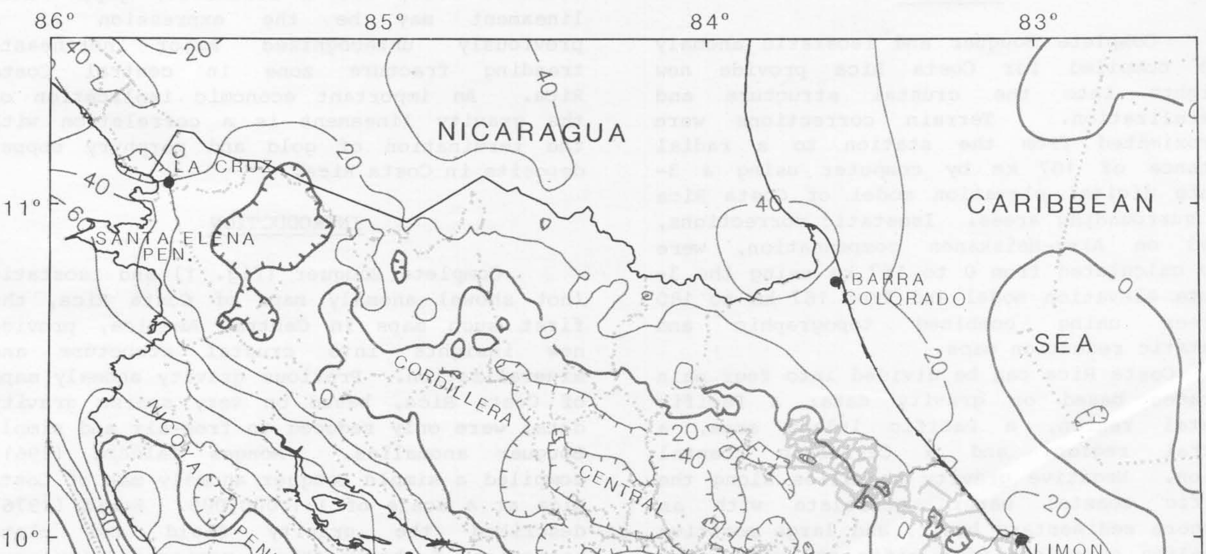

Figure 1.--Complete Bouguer anomaly map of Costa Rica with free-air anomalies offshore showing locations of gravity data and areas discussed in text. Contour interval 20 mGal.

Karki, Kivioja, and Heiskanen (1961) to a radial distance of 180 degrees.

GRAVITY ANOMALIES

Costa Rica can be divided into four main geophysical terranes based on gravity data: a Pacific coastal region, a Pacific inland area, a central region, and a Caribbean coastal region.

Gravity anomaly values are generally positive along the Pacific coast and correlate with mafic igneous rocks. Gravity anomaly values are more uniform inland and become increasingly negative in the central region over a thick volcanic complex, north of San Jose. Farther southeast, over the Coast Ranges, a major gravity low is caused by a thick sequence of sedimentary rocks. In the Caribbean coastal region, a major gravity low occurs over the Limon Basin, northwest and southwest of Limon, and reflects a thickening of sedimentary rocks. Table 1 summarizes the major Bouguer and isostatic anomalies of Costa Rica.

PACIFIC COASTAL REGION

A large negative free-air anomaly occurs offshore from the Pacific coast of Costa Rica, extends from the shelf to water depths of more than about 3,000 m, and indicates the presence of a major sedimentary basin. The amplitude of the anomaly is about 70 mGal. Reflection data of Crowe and Buffler (1985) show the presence of more than 7 km of stratified material above acoustic basement.

The largest complete Bouguer and isostatic anomaly of Costa Rica overlies the Nicoya Peninsula. Bouguer anomaly values range from about 50 to 120 mGal and isostatic anomaly values range from about 50 to 100 mGal. The anomaly overlies a terrane of mafic marine volcanic and intrusive rocks.

Mafic rocks, similar to those at the Nicoya Peninsula, are exposed in the Puerto Quepos, Osa Peninsula, and Punta Burica areas and produce Bouguer anomalies having amplitudes of about 30 to 60 mGal and isostatic anomaly amplitudes of about 20 to 40 mGal. Because the amplitudes of these anomalies are much lower than those of the Nicoya Peninsula, they are probably caused by a thinner sequence of mafic rocks. At Puerto Quepos, the gravity high is interrupted by a Bouguer gravity low with an amplitude of more than 30 mGal and is probably caused by low-density sedimentary rocks that extend inland from the sedimentary basin on the Pacific shelf.

PACIFIC INLAND AREA

The Pacific inland area is between the Pacific coastal margin and the central mountain region where gravity anomalies are of low amplitude in northern Costa Rica and are separated from the Pacific coastal region by a steep gradient. The low amplitudes and gentle gradients in this area indicate small lateral variations in the gravity field, and in part, may reflect sparse gravity data. In southeast Costa Rica over the Coast Ranges, is one of the most prominent gravity features of the country, a Bouguer gravity low with an amplitude of about 60 mGal and an isostatic gravity low of about 40 mGal. The anomaly covers about 25 by 200 km and overlies Paleogene and Neogene sedimentary rocks. The low-density sedimentary rocks are probably more than 5 km thick.

CENTRAL REGION

A major gravity low occurs over a thick low-density Quaternary volcanic complex in the Cordillera Central, north of San Jose. The low has a Bouguer anomaly amplitude of about 60 mGal and an isostatic anomaly amplitude of about 30 mGal. The low is about 60 km across and 140 km long. A small satellite gravity low occurs northwest of San Jose over a shield volcano in older volcanic rocks. In south-central Costa Rica, in the Cordillera de Talamanca region, gravity data are only available along a north-northeast-trending highway. Bouguer anomaly values range from about 0 to 10 mGal and isostatic anomaly values range from about 30 to 50 mGal. These positive anomalies have small amplitudes and appear to be related to intermediate plutonic rocks that comprise most of the region.

CARIBBEAN COASTAL REGION

A prominent feature in the Caribbean coastal region is the Limon Basin, which causes an interrupted Bouguer and isostatic

Table 1

Major gravity anomalies of Costa Rica

Location	Bouguer anomaly (mGal)	Isostatic anomaly (mGal)
HIGHS		
Nicoya Peninsula	70	50
Puerto Quepos	30	20
Osa Peninsula	60	40
Punta Burica	50	40
La Cruz	30	30
Barra Colorado	30	20
Limon	30	--
LOWS		
Offshore Pacific	-70	-70
Nicoya	-30	-30
San Jose	-60	-30
Coast ranges	-60	-40
Limon	-20	-20
Caribbean Sea	-30	-30

anomaly low with amplitudes of about 20 mGal. The basin is characterized by many northwest-trending folds and thrust faults that dip southwest. Some of these features are expressed as small gravity highs. Gravity data and drill-hole data indicate that the sedimentary rocks in the Limon Basin are more than 3 km thick.

GRAVITY DATA, STRUCTURE, AND MINERALIZATION

A two-dimensional gravity model across Costa Rica from the Pacific Ocean to the Caribbean Sea suggests that the Santa Elena, Nicoya, and Osa Peninsulas, and the Puerto Quepos area are composed of stacked layers of high-density former oceanic crust now about 20 to 30 km thick, that 'continental crust' of a lower density inceases in thickness to about 40 km below the central volcanic belt in Costa Rica, and that crustal thickness is about 25 km along the Caribbean margin of Costa Rica. The gravity model is tied to crustal refraction data (Buffler, Matsumoto, and Crowe; Matsumoto et al., 1977) that indicate a depth of about 10 to 15 km to the M-discontinuity across the Middle America Trench, a crustal thickness of about 30 km southeast of the Nicoya Peninsula, at least 20 km near the Gulf of Nicoya, and about 44 km near San Jose.

A prominent gravity lineament trending northeast separates northern and southern Costa Rica. The lineament is defined by the termination of several major gravity anomalies located at Puerto Quepos, Cordillera Central, Coast Ranges, and Limon Basin. In addition, the lineament correlates with other geologic and geophysical data including: a diffuse belt of northeast-trending faults from Puerto Quepos to the Limon Basin, the southernmost extent of large Quaternary volcanoes in Costa Rica, segmentation of the Middle America volcanic belt (Stoiber and Carr, 1974; Carr, 1984), and a seismicity gap (Pennington, Chow, and McCann, 1987). The gravity lineament may be the expression of a major northeast-trending fracture zone in central Costa Rica.

An important economic implication of the gravity lineament is the possible delimitation of gold and porphyry copper deposits in Costa Rica. The southern extent of gold occurrences in the western Cordillera Central foothills and the northern extent of porphyry copper occurrrences in the eastern Cordillera de Talamanca foothills are approximately defined by this zone.

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