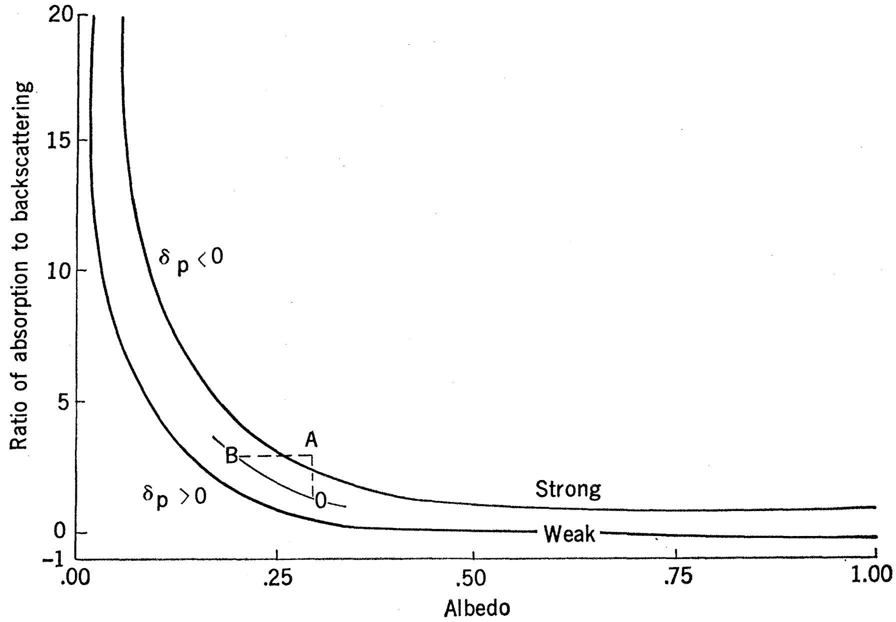


Fig. 1. Equilibrium ratio as a function of the surface albedo and the ratio of absorption to backscattering for aerosols. Both strong extinction and weak extinction are indicated.

to backscattering) the surface albedo response lags sufficiently, so that it reflects, for example, equilibrium conditions for the earlier technology. Then, any further reduction in the ratio of absorption to backscattering would result in further cooling.

Feedback effects from the warming or cooling and the interaction of the three factors introduce many complexities. For instance, a small increase in the absorption-to-backscattering ratio resulting in atmospheric heating would probably reduce the snow coverage and the surface albedo. Thus, the equilibrium ratio would change. Figure 1, which exhibits values of the equilibrium ratio as a function of surface albedo for weak and strong extinction, shows the hypothetical change in albedo (from $A$ to $B$) that would result from such a change in the absorption-to-backscattering ratio (from 0 to $A$). In practice, the transient stages indicated in Fig. 1 are probably replaced by more complex transition states.

At this point, we may now consider numerical values of the parameters described above. Values of albedo of the lower reflecting surface have been tabulated by many authors. These values include 0.05 to 0.20 for vegetation, 0.15 to 0.30 for sand and rocks, 0.40 to 0.85 for snow, and 0.06 (but dependent on solar zenith angles) for water (*4*). The albedo for clouds ranges from nearly 0 for thin clouds to 0.7 for thick stratus clouds (*5*). The average planetary albedo without clouds is 0.195 and with clouds is 0.33 to 0.38 (*4*). Representative values of the various parameters needed to determine the delta-radiation are needed. For purposes of demonstration, values used were given by or inferred from Lettau and Lettau (*6*) for urban (Kew, England), desert (La Joya, Peru), and prairie (O'Neill, Nebraska) conditions. These values are based on the model of Lettau and Lettau and on values of radiant flux observed by Robinson (*7*), Stearns (*8*), and Lettau and Davidson (*9*). Near noontime, cloudless values for a city indicate that the absorption-to-backscattering ratio has a value of 4.10 while the equilibrium ratio is 2.85. The inferred value of the absorption-to-backscattering ratio in the desert case is 0.700 (2.100 is the value of the equilibrium ratio) and in the prairie case is 0.585 (1.520 is the equilibrium value). These values result when one assumes that one-third of the scattered radiation is returned to space (as assumed by Lettau and Lettau).

Using these values, we see that the present urban aerosol–surface albedo environment would produce a warming trend if solar radiation were the only thermal process acting. On the other hand, the aerosol-albedo combination characteristic of the desert environment and prairie environment appears to produce cooling trends (again in the absence of other thermal processes).

Additional data, both in time and in space, are needed to compute representative values of the equilibrium ratio and the absorption-to-backscattering ratio for different types of aerosols. Although changes in these parameters are important, there appear to be no data concerning such changes. Further work will be necessary to remove the assumptions made in the present derivation and to include other thermal effects, particularly the infrared effects. Then the hypothesis concerning the temperature change in the atmosphere can be examined in greater detail.


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## Boconó Fault, Venezuelan Andes: Evidence of Postglacial Movement


Abstract. *Postglacial, right-lateral, strike-slip movement along the Boconó fault, measured on detailed topographic maps, averages 66 meters. The rate of movement was approximately 0.66 centimeter per year, as indicated by carbon-14 dating of associated soil. This evidence suggests that postglacial movement between the Caribbean and Americas plates occurred mainly along the Boconó fault and the north coast of Venezuela.*


There is increasing evidence (*1*) that the northern boundary of South America lies within the zone of contact between two plates of lithosphere, the Caribbean and the Americas plates (Fig. 1A). Right-lateral, strike-slip displacement is postulated to take place along this boundary (interpreted as a transform fault), with the Caribbean plate being displaced eastward with respect to the continent. The importance of the great fault zones of northern Venezuela (Boconó, Oca, and El Pilar faults) is, therefore, evident (*2*), and the sense of movement along them must reflect the interaction between the two plates. The determination of the displacement along the Boconó fault is important in the interpretation of southern Caribbean tectonics.

Only one measurement of the displacement has been made so far (*3*) by means of aerial photographs, which indicated a right-lateral displacement of 80 to 100 m. Although the displacement along the Boconó fault has been a matter of controversy (*4–6*), it has become plausible that recent movement is predominantly right-lateral strike-slip (*7, 8*). The contact between the Caribbean and South America has been postulated as a fault including the Oca and El Pilar faults (*4*), and all the movement as occurring along it. Evidence presented in this report indicates that recent movement took place predominantly along the Boconó fault and the north coast of Venezuela.

The Boconó fault displaces lateral moraines in the Upper Santo Domingo River valley (*3*). In a recent study (*9*) of the glacial geology of this region (Fig. 1B), two clearly displaced moraines were found (Fig. 2). The areas where the fault cuts the moraines are characterized by linear depressions, 20 to 100 m wide, which were eroded by postglacial streams or filled with lagoons or marshes. Minor faults, cutting the lateral moraines, show principally normal displacements to the north and are probably due to slumping. The moraines consist of till, an unsorted assemblage of clay- to boulder-sized fragments of highly metamorphosed rocks of the Precambrian (?) Iglesias group (*10*), which make up the Sierra de Santo Domingo to the south (Figs. 1B and 2A).

In order to measure the displacement of the lateral moraines in the field, we made a detailed topographic survey of the affected areas (Fig. 1, C and D). Special care was taken to define the topographic features that could be identified on both sides of the fault. These include the sharp moraine ridges (Fig. 2), small erosional valleys, and creek beds. Figures 1C and 2A show the displacement of the Victoria lateral moraine. On the topographic map, the moraine ridge is well defined and is marked by a thick line. The fault crosses the moraine almost perpendicularly to this line and produces a zone (approximately 75 m wide) of small hills and depressions. This zone breaks the continuity of the moraine ridge. Aerial photographs show that the slight curvature of the ridge is regular and continuous along its total length, which

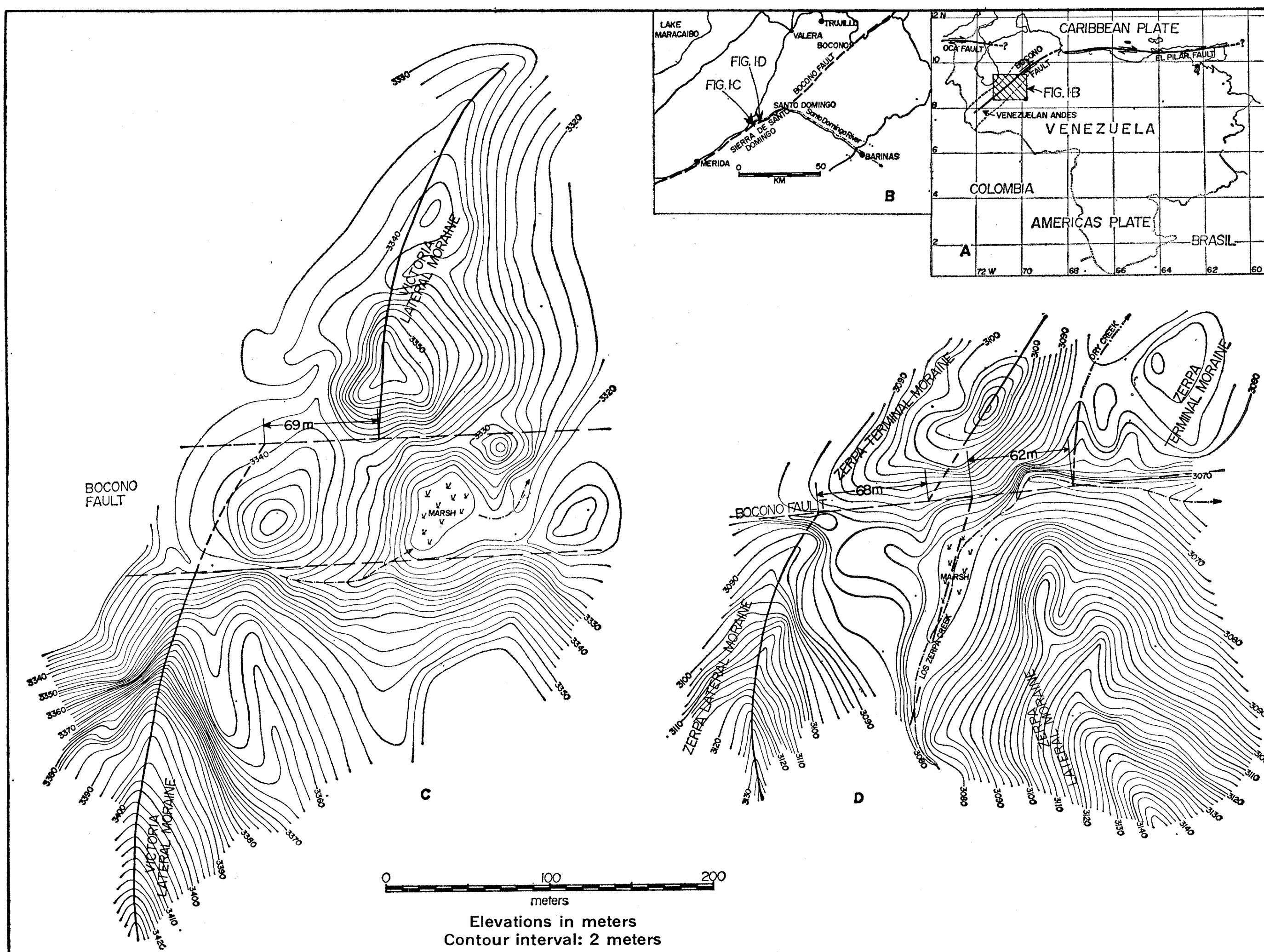


Fig. 1. (A) Index map of Venezuela showing principal faults. (B) Index map of the Sierra de Santo Domingo region showing Boconó fault. (C) Topographic map of displaced Victoria lateral moraine. (D) Topographic map of displaced Zerpa lateral moraines and creek.

is also evident on the map. Extrapolating the trend of the moraine ridge across the fault zone, the displacement measures 69 m in a right-lateral sense.

Figures 1D and 2B illustrate the displaced Zerpa lateral moraine and Los Zerpa Creek. The trends of the ridge and creek were checked against aerial photographs. In this case, the fault is a sharply defined lineament, and there is no appreciable fault zone. The displacement of the moraine ridge measures 68 m, and that of the creek, 62 m, both in a right-lateral sense.

There is little appreciable difference in elevation between the two sides of the fault attributable to vertical movements. The moraine ridges slope downward toward the terminal moraines, but no break in the slope can be observed. There are, however, other indications of vertical displacements. In the valley within the Zerpa lateral moraines, there are two terraces consisting of fluvioglacial deposits, one at 6- to 10-m elevation and another at 20- to 25-m elevation above the creek level. They are separated by a slight angular unconformity, which is interpreted as tilting due to faulting along the Boconó fault. The formation of the terraces points to probable uplift, because these features are common throughout the cordillera. Another indication of vertical movement is the elevated dry gap through which the Los Zerpa Creek flowed (Fig. 1D). This gap, which is approximately 14 m above the present creek level, is probably due to uplift of the northern block and to erosion.

The glacial deposits studied represent the effects of the last glaciation. Studies in the Sabana de Bogotá, Colombia (*11*), have shown that the Late Würm (or Wisconsin) glacial probably began by 14,000 B.C., and the postglacial times around 8,100 B.C. That glaciers had already receded from the moraine valleys in the Sierra de Santo Domingo by 5,470 ± 80 years ago (before A.D. 1,950) is shown by a radiocarbon date (*12*) of a soil sample collected at a depth of 1 m below the present valley surface (sample IVIC-722). The soil was formed after the glacier had retreated, and the date supports the conclusions from the Sabana de Bogotá. Therefore, the rate of right-lateral, strike-slip movement along the Boconó fault during postglacial times (assuming an average total displacement of 66 m) is approximately 0.66 cm per year (using a moraine age of 8,100 B.C., or 10,070 years ago). This rate of movement is reasonable when compared with that of other prominent faults, such as the San Andreas fault (*13*).

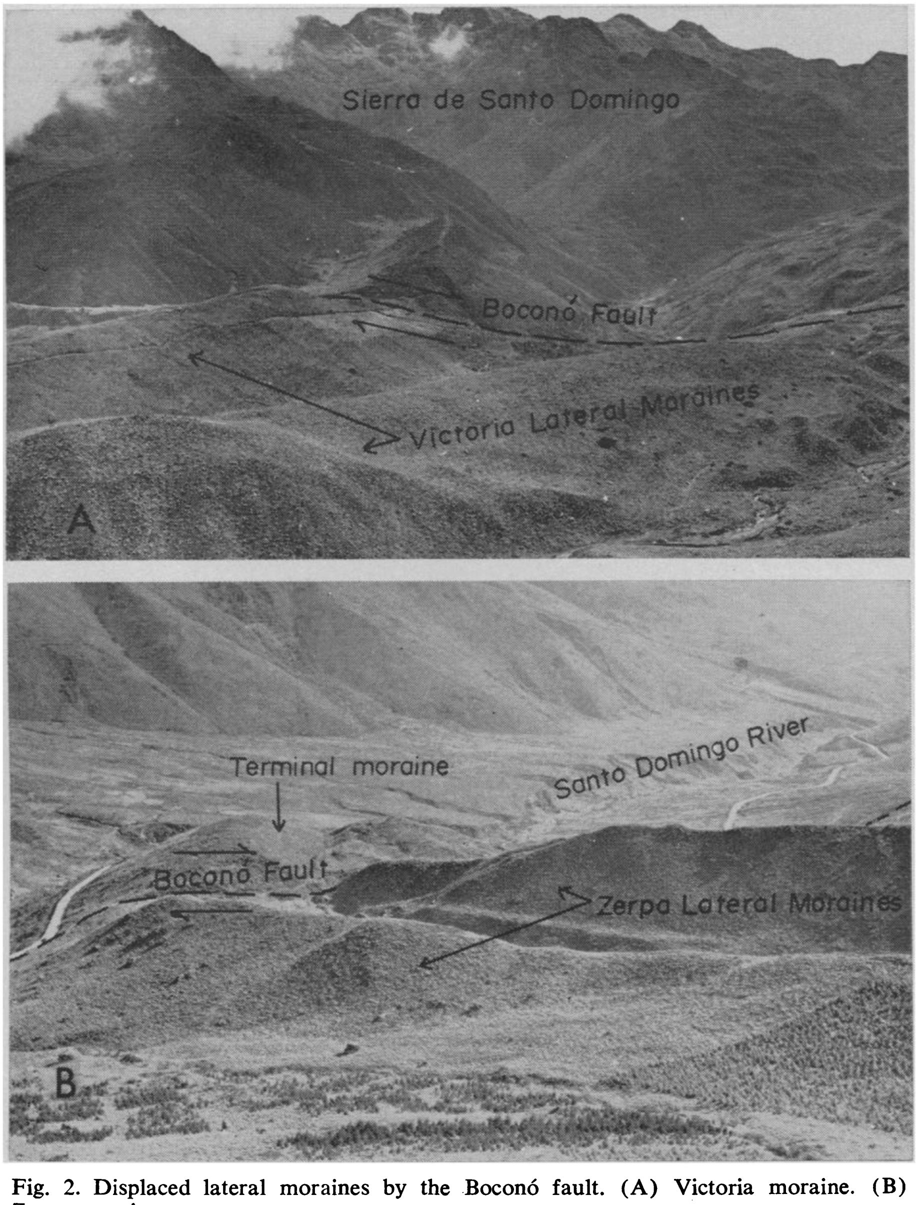


Fig. 2. Displaced lateral moraines by the Boconó fault. (A) Victoria moraine. (B) Zerpa moraine.

The evidence presented above suggests that right-lateral, strike-slip movement along the Boconó fault has been dominant at least in postglacial times. The age of the fault has been postulated as Early Mesozoic to Recent (*5, 14, 15*). Evidence has also been presented (*6, 15*) which indicates that the early movements along the fault were principally vertical (normal) and that the right-lateral, strike-slip movement is relatively young (post-Eocene or younger).

Seismically, the Oca fault (Fig. 1A), thought of as a part of the fault contact between the Caribbean and South America (*4*), is relatively quiet at present (*8*). This evidence, in conjunction with the previous evidence, indicates that most of the recent right-lateral, strike-slip movement along the boundary between the southern Caribbean plate and the Americas plate (*1*) occurs along the Boconó fault and the north coast, east of approximately 68°W.

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## Oxygen-18 Studies of Recent Planktonic Foraminifera: Comparisons of Phenotypes and of Test Parts

Abstract. *Oxygen isotopic comparisons of phenotypes of Recent Planktonic Foraminifera with both normal and diminutive final chambers are compatible with a model in which the latter develop as a response to environmental stress. Isotopic evidence shows that* Spheroidinella dehiscens *is probably not a late-stage, aberrant form of* Globogerinoides sacculifer.

We report herein comparisons of oxygen isotopes in phenotypes of the same species of Recent Planktonic Foraminifera and in test parts of individual species. We have studied the following paleontologic problems by means of paleotemperature techniques: (i) the significance of the presence or absence of diminutive final chambers (*1*); (ii) the significance of the presence or absence of bullae (platelike structures covering the primary and secondary apertures); (iii) the significance of the shape of the final chamber in *Globogerinoides sacculifer-trilobus*; and (iv) the validity of Bé's hypothesis that *Spheroidinella dehiscens* is an aberrant deep-water form of *G. sacculifer-trilobus* (*2*).

All samples for isotopic analysis, taken from core tops except where otherwise indicated, were washed in distilled water and sized. Hand-picked samples from the fraction larger than 250 $\mu$m were reacted uncrushed and isotopically analyzed by means of standard techniques (*3*). Values of $\delta$ (*4*) are reported relative to the PDB-I (Pee Dee Formation belemnite) standard. Isotopic temperatures were calculated by means of the equation given by Craig (*5*). Isotopic compositions of seawater were taken from the literature for surface stations as close as possible to the core locations (*6*, *7*). Estimates of the depths at which the Foraminifera populations occurred were made from isotopic temperatures and bathythermographic data supplied by the National Oceanographic Data Center. All results are shown in Table 1.

Berger (*1*) has suggested that the presence of diminutive final chambers in Planktonic Foraminifera from ocean sediments is indicative of growth in a stressed environment in the overlying water column. This stress may be physical (temperature, salinity) or biological (insufficient food). Our data show that phenotypes of *Globogerinoides ruber* with a diminutive final chamber from three localities have isotopic temperatures 1° to 4.5°C colder than do phenotypes with a normal final chamber from the same samples. The temperature difference is greatest in the sample from the Blake Plateau, in which the small final chamber of the test was also flattened. No significant difference in temperatures was obtained for pink and white "normal" types from one locality. If a species has a range of optimum depth at or near the surface, as does *G. ruber*, then a stressed environment in the same water column must lie in deeper, colder water. Thus, the isotopic data for this species are compatible with Berger's hypothesis.

In the case of species with distributions of optimum depth at intermediate depths, a stressed environment might lie either in cooler, deeper water; in warmer, shallower water; or conceivably in both simultaneously. *Globorotalia cultrata* lives at intermediate depths. Two samples of this species showed that the phenotype with a normal final chamber recorded essentially the same temperature as the phenotype with a diminutive final chamber. In a third sample, from an area of coastal upwelling, the "normal" phenotype recorded a temperature about 1.5°C colder. In the case of *Globoquadrina dutertrei* (*8*), another species living at intermediate depths, both phenotypes of one sample recorded virtually identical isotopic temperatures. In another sample, the form with a diminutive final chamber recorded a temperature 1.2°C colder than did the "normal" phenotype, but the difference is virtually at the level of uncertainty for these analyses. Thus our results suggest that the presence of a diminutive final chamber may be related to some environmental factors in that phenotypes may have different distributions in the water column, but that temperature is not the only factor in determining the occurrence of this phenotype.

In the case of *Globogerinoides conglobatus*, we have investigated the possible existence of temperature differences between populations with and without bullae. A bullate population in the Gulf of Mexico recorded a temperature 1.8°C warmer than the nonbullate one did. Three other samples showed no significant differences in temperatures between phenotypes.

*Globogerinoides sacculifer* and *G. trilobus* have been distinguished from each other on the basis of a saclike as opposed to a more spherical final chamber. According to Bermudez (*9*), the final chamber has the function of increasing the buoyancy of the test; thus the sacculifer form would live in shallower water than would the trilobus type. However, Jones (*10*) has observed *G. sacculifer* at greater depths than *G. trilobus* in plankton tows in the Carribbean area.

Our results show that *G. sacculifer* and *G. trilobus* are isotopically similar. In samples from the Gulf of Mexico and the Indian Ocean *G. sacculifer* recorded a slightly warmer temperature than *G. trilobus*, whereas for a few Atlantic samples, *G. trilobus* recorded a slightly warmer temperature. Isotopic comparison of the last chamber of *G. sacculifer* with the entire test for a sample from the Gulf of Mexico shows the two to be almost identical.

The data indicate that both *G. sacculifer* and *G. trilobus* form their tests at similar temperatures, and presumably at similar depths. Thus, depth stratification at any one place as reported by Jones may be related to factors other than temperature. Our results do not exclude the possibility that the final chamber in *G. sacculifer* increases the buoyancy of the test, but it does suggest that this chamber is formed at the same temperature as the bulk of the early formed parts of the test.

Finally, Bé (*2*) has suggested that *Spheroidinella dehiscens* is an aberrant terminal form of *G. sacculifer-trilobus*