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Tectonostratigraphic terrane relationships: A glimpse into the Caribbean under a cladistic approach

Amparo Echeverry [a], Gilberto Silva-Romo [b], Juan J. Morrone [a,*]

[a] Museo de Zoología "Alfonso L. Herrera", Departamento de Biología Evolutiva, Facultad de Ciencias, Universidad Nacional Autónoma de México (UNAM), Apdo. Postal 70-399, 04510 Mexico City, Mexico
[b] Departamento de Geología, Facultad de Ingeniería, Universidad Nacional Autónoma de México (UNAM), 04510 Mexico City, Mexico

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ABSTRACT

Forty one geological features were coded as cladistic binary characters and analyzed using a parsimony algorithm in order to infer the historical relationships among 24 Caribbean tectonostratigraphic terranes. The cladistic analysis produced two equally parsimonious geological area cladograms. The strict consensus cladogram depicts the group of allochthonous tectonostratigraphic terranes as a monophyletic group reflecting historical relationships that agree roughly with a Pacific origin of the Caribbean plate. We conclude that the cladistic method represents a promising analytical tool to be used in historical geology as well as a common language useful to compare geological and biogeographical results.

1. Introduction

The Caribbean plate is complex in terms of its stratigraphic record, geological structures and tectonic relationships (Silva-Romo and Mendoza-Rosales, 2009). The geological models formulated to explain the origin and evolution of the Caribbean plate are diverse and often contradictory, going from fixed models postulating a more or less in situ origin (Le Pichon, 1968; Meyerhoff and Meyerhoff, 1972; Meschede and Frisch, 1998) to mobilistic models postulating a Pacific allochthonous origin (Freeland and Dietz, 1971; Malfait and Dinkelman, 1972; Burkart, 1983; Pindell and Barrett, 1990; Iturralde-Vinent and MacPhee, 1999; Kennan and Pindell, 2009). Allochthonous models for the Caribbean though not simple provide a better explanation for some of the major Cenozoic tectonic events in southern Mexico (Silva-Romo, 2008), and according to Kennan and Pindell (2009), only Pacific origin models for the Caribbean can explain adequately some geological features of northwestern South America such as the accretion of multiple arc fragments to western Ecuador and Colombia.

Biogeographical data generally are interpreted in the context of paleogeographic hypotheses, and the lack of integration with geological data has been a major problem (Young, 1990). A few decades ago, biogeographers began presenting geological information in a hierarchical manner. Rosen (1978) and Platnick and Nelson (1978) suggested the construction of geological area cladograms derived from specific analyses of geological/geographical characters but did not demonstrate how they might be constructed. Rosen (1985) searched for common factors in some of the allochthonous models by translating available scenarios into area cladograms.

Cladistics is a method of hierarchical analysis which has been used extensively in phylogenetic reconstructions where morphological and molecular characters are analyzed using a parsimony algorithm in order to group taxa on the basis of shared derived characters or synapomorphies. The cladistic method has also been applied in biogeography. Cladistic biogeography assumes a correspondence between taxonomic relationships and area relationships based on an analogy between biogeography and systematic using taxa as characters. General area cladograms represent hypotheses on the biogeographic history of the taxa analyzed and the areas where they are distributed (Morrone, 2009). Disciplines such as linguistics (e.g., Rexová et al., 2003) and others concerned with historical analyses have also used cladistic methods. Recent comprehensive treatments of cladistics can be found in Schuh and Brower (2009) and Wiley and Lieberman (2011).

Young (1986) applied a cladistic approach to some problems of Paleozoic paleogeography in an attempt to reduce the complexity of ideas in the literature by representing competing hypotheses on branching diagrams. Young (1995, 2010) considered cladistics as a rigorous analytical method that is applicable to any hierarchical data set and because terrane fragmentation is equivalent to phylogenetic splitting of biological taxa, the standard algorithms for

* Corresponding author. Tel.: +52 5556224945; fax: +52 5556224828.
E-mail addresses: echeverryceae@gmail.com (A. Echeverry), silvarg@servidor.unam.mx (G. Silva-Romo), juanmorrone2001@yahoo.com.mx (J.J. Morrone).

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parsimony analysis may be applied directly. Terrane accretion is a special case according to this author, one for which appropriate algorithms are not yet available. Craw (1988) and Padilla and Halffter (2007) constructed geological area cladograms derived from geological characters, although not exclusively because they also used landscape and soil features, which are not geological features themselves but products of geological processes. Their units of analysis were areas of endemism in the former and geomorphological units in the latter.

This paper explores how the cladistic method performs when it is used to analyze geological characters of a sample of tectonostratigraphic terranes in the Caribbean. Our objectives are twofold: (1) to obtain a geological area cladogram(s) derived from parsimony analysis of geological characters in order to infer historical relationships among tectonostratigraphic terranes; and (2) to test the monophyly of the allochthonous tectonostratigraphic terranes in the Caribbean.

2. Material and methods

2.1. Units of analysis

Tectonostratigraphic terranes were used as units of analysis. As defined by Howell et al. (1985: 4), "A tectonostratigraphic terrane is a fault-bounded package of rocks of regional extent characterized by a geologic history which differs from that of neighboring terranes. Terranes may be characterized internally by a distinctive stratigraphy, but in some cases a metamorphic or tectonic overprint is the most distinctive characteristic. In general, the basic characteristic of terranes is that the present spatial relations are not compatible with the inferred geologic histories".

Twenty four Caribbean tectonostratigraphic terranes were analyzed (Fig. 1), previously defined by the following authors: Sedlock et al. (1993) (six from Mexico; one of them includes Belize and Guatemala); Rogers et al. (2007a) (four from Honduras, El Salvador and Nicaragua); Meschede et al. (1988) (three from Costa Rica); Kennan and Pindell (2009) (five from Colombia); García-Casco et al. (2001) and Cobiella-Reguera (2003) (three from Cuba); and Lewis et al. (2002) (three from Dominican Republic). Additionally we used the North American tectonostratigraphic terrane (Sedlock et al., 1993) in order to root the resulting cladogram(s). The terranes used for the analysis were chosen because they are well documented in terms of their geological features and as an example for the use of the cladistic method since these units represent 'natural' geological entities. Other types of geological units can be used to carry out a cladistic analysis if enough geological characters can be identified for the selected areas. Table 1 lists the faults representing the boundaries of the tectonostratigraphic terranes.

2.2. Geological characters

Based on published studies (Table 2), we defined 41 geological characters which were coded as binary characters (Table 3). The selection of these characters was based on two criteria: the accuracy of their description in the sources consulted and the occurrence of these specific characters in two or more tectonostratigraphic terranes which makes the comparative analysis possible. Some additional comments have to be made with respect to the geological characters used here. In order to make the characters more precise, simplification of the complexity of criteria used by geologists was required. Age itself was not used as a character but the dated rock types. Rocks of a given age are an essential component of the description of the tectonostratigraphic terranes and as the rest of the geological characters listed in Table 3 they represent diagnostic features of these terranes. And lastly, although some geological characters like "greenschist facies" might seem too broad, this is not the case because it implies specific information about mineralogy and geochemistry.

2.3. Analysis

A $r \times c$ matrix was constructed, where the rows (r) represent tectonostratigraphic terranes and the columns (c) represent geological characters (Appendix A). Each matrix entry is '1' when a given geological character is present and '0' if it is absent. A '?' is included

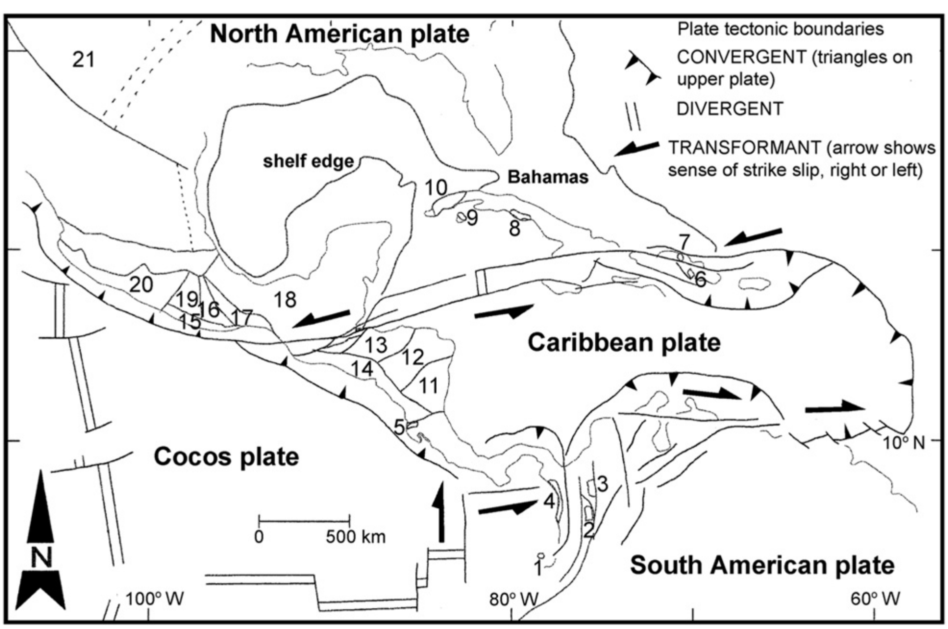

Fig. 1. Caribbean tectonostratigraphic terranes: 1, Gorgona; 2, Arquía/Quebradagrande complex; 3, Antioquia; 4, Chocó (Kennan and Pindell, 2009); 5, Santa Elena, Esperanza, Matapalo complex (Meschede et al., 1988); 6, Loma Caribe; 7, Duarte/Maimón complex (Lewis et al., 2002); 8, Escambray; 9, Pinos; 10, Guaniguanico (García-Casco et al., 2001; Cobiella Reguera, 2003); 11, Siuna; 12, Eastern Chortís; 13, Central Chortís; 14, Southern Chortís (Rogers et al., 2007a, 2007b); 15, Chatino; 16, Zapoteco; 17, Cuicateco; 18, Maya; 19, Mixteco; 20, Náhuatl; 21, North America (Sedlock et al., 1993).
Modified from Silva-Romo (2008).