Solving the Cool Tropical Paradox: Paleotemperature and Paleoprecipitation Estimates Using Leaf Megafossils of a Tropical Paleocene Site in Northern Colombia

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During the last two decades the scientific community have been intrigued to know the role of the tropics on global climate during past greenhouse events. However, the lack of empirical data from low latitudes and the discrepancies between those data have impeded to quantify the causes that generated past greenhouse states.

One of the most extreme global warming took place 60 million years ago during the early Paleogene. That event was characterized by ice-free poles, polar coastal water temperatures oscillating between 10-15°C, deep ocean temperatures approaching 8-12°C, and warm temperatures at high latitudes and mid-latitude continental interiors (Greenwood and Wing, 1995; Tripati et al., 2001; Zachos et al., 2001).

Nevertheless, while the high latitudes show strong evidence of this global warming, the low latitudes fail to do that. Tropical sea-surface temperatures (SSTs) estimates based on isotopic signals of planktonic foraminifera have suggested that tropical SSTs were stable or even several degrees cooler (<23°C) than modern values (Zachos, 1994). On the contrary, SSTs estimates based on oxygen isotopes and/or Mg/Ca ratios of planktonic foraminifera, gastropods and molluskan shells (Kobashi et al., 2001; Pearson et al., 2001; Tripati and Zachos, 2002; Zachos et al., 2003) suggest tropical warm temperatures (26-32°C) throughout the early Paleogene. The disagreement between SSTs during past "greenhouse" intervals such as the Cretaceous and early Paleogene has been called the "cool tropics" paradox (D’Hondt and Arthur, 1996; Pearson et al., 2001).

Four major hypotheses have been proposed to explain the warm climate of the early Paleogene. The first hypothesis suggests that during the early Paleogene high levels of atmospheric carbon dioxide (CO₂) warmed the entire globe even in tropical latitudes (Shellito et al, 2003). This hypothesis would imply tropical temperatures approaching ~30°C with 500 ppm and ~34°C with 2000 ppm of CO₂. The second hypothesis states that increasing the heat transport by the ocean would warm mid and high latitudes and would keep tropical latitudes approximately at the same temperature or even cooler than today. In other words the ocean would be responsible for the low latitudinal temperature gradient (the "cool tropics"). However this hypothesis would need a physical mechanism to produce a realistic climate. Hotinski and Toggweiler (2003), have produced a general circulation model where a circumglobal Tethyan passage since the Jurassic to the Miocene might have increased the pole-ward ocean heat transport during the early Paleogene. A third hypothesis proposes that high atmospheric methane concentrations would be able to produce polar stratospheric clouds necessary to warm high latitudes without overly warming the tropics (Sloan and Pollard, 1998). Finally, a fourth hypothesis proposes that a moderately reduced axial tilt on Earth’s obliquity, a seasonally ice-free Arctic Ocean and four times the pre-industrial level of atmospheric CO₂ (Sewall and Sloan, 2004), would be responsible to warm high latitudes without increasing tropical temperatures as greenhouse gases fail to do.

In order to estimate the reliability of the different hypotheses proposed to explain the climate of the early Paleogene, in this study I obtained the first estimates of mean annual temperature (MAT) and mean annual precipitation (MAP) for any tropical latitude on continental zone during the late Paleocene. To reconstruct the paleoclimate I used fossil leaves.

The study region (Fig. 1) is located in the coalmires of Cerrejón, Guajira Peninsula, Colombia (11.13 N, 72.57 W). In this mine is exposed the Cerrejón Formation (Rancheria Basin) which has been dated as late Paleocene, approximately 60 million years old. During 2003 and 2004 the Cerrejón coal mine was explored for the first time. I discovered four localities with more than 100 specimens of fossil plants and five localities with less than 40 specimens. The localities were found at Expanded West, Tabaco 1, Tabaco High Dip and La Puente Pit. A total of 858 specimens of fossil leaves were collected and classified to estimate paleoclimatic parameters.
To calculate the MAT and MAP I used two methods: the leaf margin analysis (Wilf, 1997), which is based on the positive relationship between MAT and the proportion of woody dicot species in a floral sample that has entire (untoothed) leaf margins, and the leaf area analysis (Wilf et al., 1998), which is based on the relationship between the area of the leaves and MAP.

Among the Cerrejón flora I identified 55 morphotypes of fossil leaves, 41 dicots, 8 monocots, 1 cycad, 1 conifer and 4 ferns. Of the 41 dicot morphotypes found I used 39 dicots only to obtain the MAT. The proportion of entire-margined morphotypes in the flora is 74% so the leaf margin analysis gives an estimated MAT of 23.8°C ± 2.1°C. The MAP is estimated as 324 cm/year with a range between +140 cm and – 98 cm.

Using the MAT and MAP I tested the paleoclimatic simulations and their hypothesis. The first hypothesis which requires high levels of atmospheric CO₂ implies that tropical temperatures should be over 30°C as minimum with 500 range of MAP calculated on the Cerrejón flora. Personal communication), which is in agreement with the model gives a MAP up to 250 cm/year (J. O. Sewall, personal communication), which is in agreement with the range of MAP calculated on the Cerrejón flora.

To conclude the MAT estimated in this study indicates that while there was an extreme warming at mid and high latitudes during the early Paleogene, tropical temperatures on coastal-continental zones were not warmer than in the present, producing a low latitudinal temperature gradient, so the “cool tropical paradox” is true and is present in continental zones. Several are the possible mechanisms to keep the tropic cool: 1) increasing the pole-ward ocean heat transport (under circumglobal Tethyan passage) or 2) under polar stratospheric clouds. On the contrary the hypothesis based exclusively by high levels of CO₂ atmospheric does not reproduce the cool tropical climate that has been found in this study. The paleoclimate community must take into account the estimates obtained in this study and evaluate additional factors (feedbacks) to reproduce a realistic climate using models with dynamic vegetation for the early Paleogene.

Finally the Cerrejón flora represents the oldest rainforest known so far in any tropical latitude. Large leaf size, many large leaved monocots, high proportion of leaves that preserve acuminate apex and insect herbivory common prove the presence of this rainforest. In addition, the flora is dominated by angiosperms and some floristic affinities typical from the modern South American rainforest such as Leguminosae, Euphorbiaceae, Lauraceae, Sapotaceae, Araceae Menispermaceae and Zingiberiales has been recognized (Fig. 2). The next work on Cerrejón flora will be identify the effect caused by this paleorainforest on global climate, specially in the “cool tropics paradox” and to explore the origin of the rainforest in South America.

References

Figure 2. Cerrejón Flora. A. Zingiberales; B. Euphorbiaceae; C & D. Leguminosae; E. Menispermaceae; G. Sapotaceae; F & H. Without floristic affinities. Scale bars (5 cm), except for A (10 cm)