XX CONGRESO COLOMBIANO DE GEOLOGÍA
CALI 2025

Recepción de resumenes CCG

Titulo / Autores / Institución

TITULO DE LA PONENCIA

Fossil plants aren't just pretty: They are vital to reconstructions of paleoenvironment and paleoclimate

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Estilo preferido

ESTILO DE PRESENTACIÓN

- Presentación Oral

Categoría del resumen

ÁREA TEMÁTICA

Geología histórica y clima

LÍNEAS TEMÁTICAS GHC

Cambio climático

Resumen

PALABRAS CLAVE

Paleobotany, Taxonomy, Paleoclimate

CONTENIDO DEL RESUMEN

The field of paleobotany has been going strong for more than a century, and paleobotanists have continued to evolve new ways of utilizing plant remains to understand ecosystems and climate of the geologic past. Paleobotanists were initially mainly focused on taxonomic descriptions, and were highly successful at describing plant specimens from the Silurian when they breached land, up until the late Paleozoic when forest ecosystems were fully developed. Much of this success was a product of relatively low diversity in early ecosystems, as well as spectacular cellular level preservation in coal balls and ironstone nodules that allowed for the reconstruction of whole plants from the roots to the leaves on the canopy. Coal ball preservation

ended as a major preservation style after the Carboniferous period, making it more difficult to reconstruct plants and determine botanical affiliations. Additionally, the evolution of angiosperms led to much greater species diversity, and the advent of ecosystems such as tropical rainforests meant that almost all ecosystems were more diverse than in the Paleozoic when preservation modes were also more helpful.

Much of the effort focused on Mesozoic and Cenozoic plants switched to using plant fossils as biodiversity metrics through time. This included the study of mass extinction events, which were defined by major changes in vertebrate assemblages, but understudied for the coeval plant response. This was true for the K-Pg boundary, where until the late 1980s it wasn't understood that plant extinction also coincided with the dinosaur die-off (Johnson et al., 1989). Studies focused on the post-K-Pg ecosystem recovered in tandem, driven by plants and climate change (Lyson et al., 2019). What is notable is that the major data for the plant extinction and radiation in the Paleogene did not depend upon in-depth knowledge of their modern botanical affinities; only the ability to differentiate taxa and the ability to track plant response to climate change were needed.

Plant sensitivity to climate and the surrounding environment has been one main direction of expansion in paleobotany. Paleobotanists recognized relatively early that plants are sensitive to climate. Now known as Leaf Margin Analysis, Bailey and Sinnot (1915) were the first to recognize that the margins of leaves were good predictors of temperature. This type of quantitative approach was greatly expanded by Jack Wolfe (1992) using his multivariate statistical approach called CLAMP (Climate Leaf Analysis Multivariate Program), and further refined by the DILP (Digital Leaf Physiognomy) approach that reduced error and refined the practice (Royer, 2012). Both approaches allowed for greater extraction of climatic parameters.

In the past three decades, the application of the traits preserved on fossil plant leaves, and particularly leaves with cellular level preservation, has been where the discipline has expanded the most. The recognition that plants are sensitive to the atmospheric concentration of CO2 by Woodward (1987), and respond by adjusting the number, size, and distribution of their stomatal pores has led to widespread development of paleo-pCO2 proxies (CenCO2PIP), 2023). The original stomatal density and stomatal index approaches have been augmented by more elegant models that approximate the photosynthesis process, simplified to function with data that can be collected from fossil plant compression material (Franks et al., 2014; Konrad et al., 2021). We have tested these proxies for CO2 estimation in deep time using an outdoor elevated CO2 experiment, called the Fossil Atmospheres experiment, using Ginkgos because of their long fossil record (Sher et al., 2022). Our experimental tests have revealed the strengths and weaknesses of these proxies, and provide signposts for the future direction of the field.

Some of the most exciting recent developments in paleobotany involve the shapes and sizes of epidermal cells on leaves. The upper side of the leaf is sensitive to the light environment, and are therefore influenced by canopy thickness, which covaries with many other ecosystem indicators. Proxies have been developed for this canopy thickness (Leaf Area Index) using leaf phytoliths (Dunn et al., 2015). Recently, we have been developing methodologies that utilize the cellular outlines of modern and fossil leaf material, developing automated strategies to increase the pace of data collection and sample size, and to link the traits back to other aspects of climate, such as temperature and precipitation. Bringing us back to the beginning, the latest efforts by paleobotanists have been to use Artificial Intelligence through computer vision learning practices to rapidly identify macrofossil leaves (Wilf et al., 2021), and through the application of different wavelengths of light.

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