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Cenozoic basin thermal history reconstruction and petroleum systems in the eastern Colombian Andes

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Late Mesozoic-Cenozoic retro-arc foreland basins along the eastern margin of the Andes in South America host the world′s best detrital record for the study of subduction orogenesis. There, the world′s most prolific petroleum system occur in the northernmost of these foreland basin systems, in Ecuador, Colombia and Venezuela, yet over 90% of the discovered hydrocarbons there occur in one single province in norteastern Venezuela. A successful industry-academy collaboration applied a multidisciplinary approach to the study of the north Andes with the aim of investigating both, the driving mechanisms of orogenesis, and its impact on hydrocarbon accumulation in eastern Colombia.

The Eastern Cordillera is an inversion orogen located at the leading edge of the northern Andes. Syn-rift subsidence favored the accumulation of km-thick organic matter rich shales in a back-arc basin in the early Cretaceous. Subsequent late Cretaceous thermal subsidence prompted the accumulation of shallow marine sandstones and shales, the latter including the Turonian-Cenomanian main hydrocarbon source-rock. Early Andean uplift since the Paleocene led to development of a flexural basin, filled with mainly non-marine strata. We have studied the Meso-Cenozoic thermal evolution of these basins through modeling of a large thermochronometric database including hundreds of apatite and zircon fission-track and (U-Th)/He data, as well as paleothermometric information based on vitrinite reflectance and present-day temperatures measured in boreholes. The detrital record of Andean construction was also investigated through detrital zircon U-Pb geochronometry in outcrop and borehole samples. A comprehensive burial/exhumation history has been accomplished through three main modeling strategies. First, one-dimensional subsidence was used to invert the pre-extensional lithospheric thicknesses, the magnitude of stretching, and the resulting heat flow associated to extension. The amount of eroded section and the maximum temperatures for various stratigraphic units at each locality were calibrated with thermochronometry. Subsequently, two-dimensional thermal models were constructed using thermokinematic modeling of sequentially restored structural cross-sections, for which abundant thermochronometric data was inverse modeled using FETKIN, a software developed within this collaborative project. Finally, the spatial and temporal distribution of source rock exhumation was documented with quantitative modeling of U-Pb data.

The results reveal that early Cretaceous back-arc development occurred along a pre-stretched, 90 km thick lithosphere with stretching factors of up to 1.8. Such conditions led to an early Cretaceous high heat flux which, along with rapid syn-rift subsidence, resulted in an early maturation of the potential early Cretaceous source rocks, limiting their ability to expulse hydrocarbons later on, during the petroleum system′s critical moment. Our results reveal the competing roles of tectonic inheritance and climate-tectonic feedbacks in the construction of the North Andes and, importantly, illustrate that the Oligocene main inversion of the Eastern Cordillera was a key element for assessing the size of active hydrocarbon kitchens and is a decisive element to consider for volumetric calculations of yet-to-find resources. Our work in the northern Andes demonstrated that thermal and structural kinematic modeling in thrust-belts is greatly improved by a careful usage of geochronological data, which involves robust modeling strategies.