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Using gas geochemistry to delineate structural compartments and assess petroleum reservoir-filling directions: A Venezuelan case study

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Here we examined the light hydrocarbon and nitrogen content and isotopic signatures of eleven gaseous samples in order to evaluate lateral intra-reservoir continuity in a Venezuelan reservoir in the central area of Lake Maracaibo Basin. At least three single compartments, located in the northern-central and southern parts of the reservoir, are revealed by nitrogen concentrations showing clear step-like compositional breaks. The occurrence of step-breaks was also supported by the isotopic signature of individual hydrocarbon compounds in the range of C_1–C_4 alkanes. Samples presented only slight differences in N_2 and hydrocarbon gas compositions within the central and northern parts of the reservoir, and therefore it was not possible to infer structural barriers in coherence with the geological section. Some oil bulk parameters corroborate gradual changes that provide additional information on the reservoir-filling history, thus suggesting that the lateral physical–chemical equilibrium of fluids was not reached in this reservoir.

1. Introduction

Organic geochemistry has played a key role in hydrocarbon exploration in recent decades. In particular, the application of gas geochemistry to reservoir studies and production engineering has attracted considerable attention (Kaufman et al., 1990; Bazan, 1998; Levaché et al., 2000; among others). Several case studies have reported the use of oil and gas compositional variations to investigate reservoir compartmentalization (i.e., Schoell and Jenden, 1993; Hwang et al., 1994; Larter and Aplin, 1994; Holba et al., 1996; Beeunas et al., 1999; Tocco and Alberdi, 1999).

Reservoir geology and engineering are being integrated by means of new analytical techniques that provide information on the natural complexity of oils. For example, a novel complementary method based on Fourier Transform Infra Red (FTIR) spectroscopy was recently proposed (Permanyer et al., 2002) to determine crude oil reservoir compartmentalization. In addition, time-lapse geochemistry (TLG) technology was used for two reservoirs in the deep-water Gulf of Mexico to locate and study petroleum barriers, thus yielding valuable information about reservoir behavior (Milkov et al., 2007).

The study of low molecular-weight fractions (<C_{15}), and more recently gas fingerprints to evaluate the lateral and vertical continuity of reservoirs is based on the premise that light fractions from a single hydrocarbon column (continuous reservoir) have similar chemical compositions, whereas production from separate hydrocarbon columns (different sand/fault blocks) implies significantly different compositions (England et al., 1995). In this context, the use of gas isotopes to assess reservoir fluid heterogeneity has proved useful to further our understanding of reservoir connectivity (Rein and Schulz, 2007). The reasons for reservoir chemical and isotopic differences in discontinuous hydrocarbon columns are not fully understood and therefore a detailed study of each reservoir is required (Wavrek et al., 2001). Compositional similarities are thought to be the result of homogenization within the compartments after diffusion, convection (density-driven), and fluid–rock interactions have reached equilibrium (Smalley et al., 1994). England (2007) reviewed the applications of reservoir geochemistry from a reservoir engineering point of view and concluded that it is useful for addressing issues related to production allocation, reservoir compartmentalization, and the prediction of gravitational gradients. Beeunas et al. (1996) described in two reservoir sands without communication in the Gulf of Mexico

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a similar situation when compared to the present case study, determining carbon isotopic variations in methane, ethane, and propane.

It is also pertinent to note that nitrogen is one of the main non-hydrocarbon gas in many petroliferous basins (Jenden et al., 1988). Although nitrogen in natural gases is probably derived from organic matter in the sedimentary column (Rohrback et al., 1983), there are other subsurface nitrogen sources such as dissolved air in groundwater, mantle-derived N_2 in areas of recent magmatic activity, and N_2 released from metasedimentary rocks during metamorphism (Gold and Held, 1987; Krooss et al., 1993). While N_2 concentrations have been used mostly to allocate gas mixtures in storage containers (Schoell and Jenden, 1993), molecular nitrogen concentration in gases can also be applied to reservoir characterization (Ballentine and Sherwood Lollar, 2002). Consequently, there is growing interest in modeling N_2 generation (Littke et al., 1993). To date, most nitrogen studies have been done in gas-source rocks, such as coal or source rock containing humic organic matter (Clayton, 1997; among others); however, nitrogen generation from marine organic matter has received less attention (i.e., Kotarba and Nagao, 2008).

Given the preceding considerations, here we integrated diverse geochemical data with the aim to elucidate lateral intra-reservoir continuity in a Venezuelan reservoir (central sector of Lake Maracaibo Basin). For this purpose, we applied a relatively recent approach to integrate information about the compositional signatures of the C_1–C_4 alkanes and molecular nitrogen with isotopic analyses of individual hydrocarbons in gaseous samples. Furthermore, API gravities, V/Ni ratios and sulfur contents in sampled oils are also provided to complement and contrast data obtained from gases.

2. Petroleum exploitation context

The Maracaibo Basin is located in north-western Venezuela (Fig. 1a), an area comprising mainly the state of Zulia and also those of Falcón, Mérida, Táchira, and Trujillo. The Lake Maracaibo Basin (containing 700 oil-producing fields after drilling about 16,500 wells) covers an area of approximately 50,000 km^2, with an estimated sediment volume of 250,000 km^3 over a pre-Cretaceous basement (González de Juana et al., 1980).

The main petroleum source rocks in the study area are the Cenomanian–Campanian La Luna Formation (Erlich et al., 2000) and, to a lesser extent, the Aptian–Albian Apón Formation (Machiques Member), although other rock units also generate hydrocarbons (Talukdar et al., 1986). The Lake Maracaibo Basin

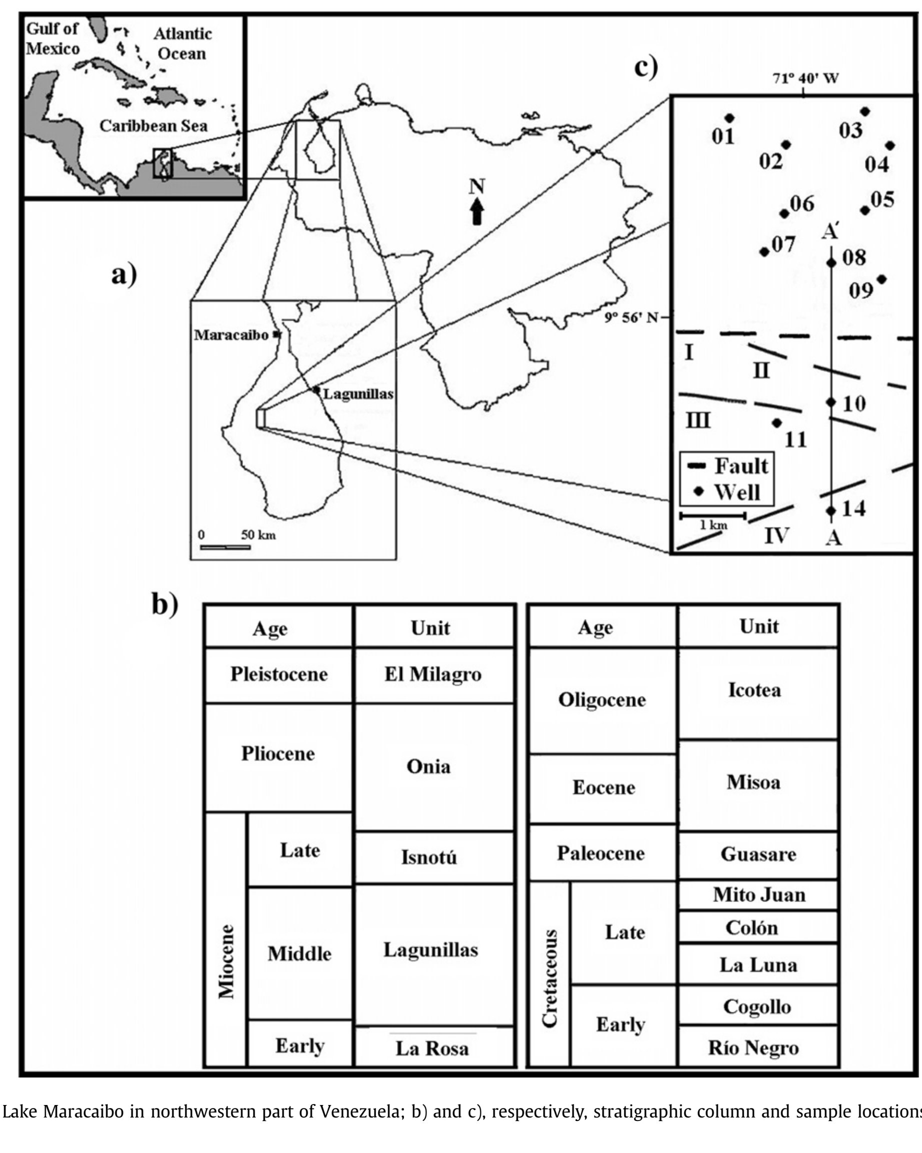

Fig. 1. a) Map of Lake Maracaibo in northwestern part of Venezuela; b) and c), respectively, stratigraphic column and sample locations in the study area.