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Non-seismic and Non-conventional Exploration Methods for Oil and Gas in Cuba

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Foreword

The successful exploration of hydrocarbon deposits culminates with the drilling of discovery wells of oil and gas reservoirs. The presence of a reservoir implies the formation and migration of hydrocarbons and their subsequent accumulation in a structural–stratigraphic geological trap. A deposit can be constituted by several reservoirs located at different depths, with different pressures and temperatures and with different types of hydrocarbons. They maintain in common to present a mixture of organic compounds with a great diversity of chemical compositions formed mostly by carbon and hydrogen (paraffinic, naphthenic, and aromatic series with the presence of oxygen, nitrogen, sulfur, and other impurities). All this diversity, together with the geological characteristics of each region, makes it more complex to detect them by conventional exploration methods, in addition to making this process more expensive. The optimum exploration technology to detect and map structures from the surface to depths of thousands of meters is seismic, in its different variants. However, the expected results are not always obtained for different reasons. For example, there is not always a marked acoustic impedance contrast between the different horizons of the geological section. Therefore, the use of non-seismic and non-conventional methods, that help to delimit and specify the results of the exploration, is justified.

There are many and diverse non-seismic and non-conventional methods. In Cuba, we have application experiences with positive results in several areas of the Cuban gas–oil regions. The authors of this monograph set out to show these positive experiences, using as evaluation criteria:

- The local gravimetric maximums, which reflect positive structures (by the more dense volcanic and carbonate uplifts), sometimes within the limits of certain values of the aeromagnetic field reduced to pole;
- Minimum values of the K/Th ratio, with local maximums of U (Ra) in its periphery;
- Positive residual geomorphic anomalies;
- Remote sensing anomalies;
- Anomalous indications by the ***Redox Complex***.

Regarding the morphotectonic regionalization of the seas south of Cuba in shallow, transitional, and deep waters, applied to the region of the Batabanó, Ana María and Guacanayabo Gulfs, the Cayman Ridge, the Yucatan Basin and the Bartlett Trench, their results allowed to establish the areas of greatest prospective interest, in case of an active petroleum system.

This monograph compiles a large part of the knowledge and experience of the authors, applied to specific areas (Ciego de Ávila, Las Villas, and Sancti Spiritus, in central Cuba, and the Habana–Matanzas region in western Cuba), in order of complementing the results of seismic investigations, often not very resolutive. The results presented here will serve as reference material for specialists who wish to deepen the application of non-seismic and non-conventional methods for hydrocarbon exploration in areas with a complex geological structure.

The authors: Manuel E. Pardo Echarte, Geophysical Engineer, Doctor of Geological—Mineralogical Sciences, Osvaldo Rodríguez Morán, Geophysical Engineer, Doctor of Technical Sciences and Orelvis Delgado López, Geological Engineer, Master in Geophysics, have more than 15 years of work experience at the Petroleum Research Center, where they have spent most of their working lives in the Geology Basic Technical Scientific Unit.

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Preface

In various geological situations, seismic data provide little or no information about whether a trap is loaded with hydrocarbons or not. In other cases, when the acquisition is difficult and extremely expensive, or the quality of the information is poor due to geology or unfavorable surface conditions, it is the non-seismic exploration methods and, in particular, the unconventional methods of exploration, the only ones that can provide information about subtle stratigraphic traps. Besides, it is well documented that the generality of hydrocarbon accumulations has leaks or microseepage, which are predominantly vertical, as well as that they can be detected and mapped using various non-conventional and non-seismic methods of exploration. The benefits in the use of non-seismic and non-conventional exploration methods, integrated with geological data and conventional methods, translate into a better evaluation of prospects and exploration risk; such is the purpose that the book seeks.

In Cuba, there are two petroleum provinces, one north and another south. In the Northern Province, the main geological scenario where hydrocarbons are produced is related to a folded and thrusted belt, making it very difficult to identify, by seismic, the elements that make up the petroleum systems (source rocks, reservoirs, and seals). The South Province is characterized by tertiary basins deposited on volcanic rocks and ophiolites over thrusted on the North American continental paleomargin. In this province, the seismic is more resolutive than in the north, but there is the difficulty that the rock eval studies have not revealed the source rocks existing in that territory, which are demonstrated by the hydrocarbon shows in wells and on the surface. The majority of the hydrocarbon shows have been studied by the techniques of chromatography coupled to mass spectrometry (biomarkers) and grouped into genetic families that have subsequently been correlated with the source rocks identified in the Northern Petroleum Province through rock eval studies. From the previous data, the geographical limits and stratigraphic extensions of the petroleum systems in the Northern Petroleum Province have been defined. These spatial and temporal characteristics were extrapolated to all that territory, and in this way, the active systems were defined in the different regions of the north of the country. Thus, four stratigraphic intervals of source rocks (Callovian Middle

Jurassic, Oxfordian Upper Jurassic, Tithonian Upper Jurassic—Barremian Lower Cretaceous and Aptian Lower Cretaceous—Turonian Upper Cretaceous) and three oil genetic families (I, II, and III) were identified. In the case of the Southern Province, although there are several hydrocarbon shows that indicate the presence of active source rocks, the lack of knowledge of them does not allow the definition of petroleum systems. The biomarker data indicate that in the southern basins of Cuba, the petroleum systems identified in the Northern Province can coexist with other systems. These are associated with source rocks of the Upper Cretaceous or Tertiary age, according to the presence of Oleanano in oil shows obtained in the Ana María 1 well and in the sands of the keys of the Guacanayabo Gulf.

A geological task posed to the geological–geophysical processing and interpretation consisted in the mapping of possible new gaso-petroleum targets that will base the exploration in the Pina–Ceballos (northeast of the Central Basin) and Sancti Spíritus regions. In addition, an evaluation by recognition works of the ***Redox Complex*** of several of these possible new targets was envisaged. The mapping of the areas of interest was proposed based on the presence of a complex of indicator anomalies, mainly gravimetric, aeromagnetic, and airborne gamma spectrometric. To this end, the gravimetric (Bouguer reduction 2.3 t/m^3) and aeromagnetic field (reduced to pole) at 1:50,000 scale, the airborne gamma spectrometry (channels K, Th, and U (Ra)) at scale 1:100,000 and the Digital Elevation Models 90 × 90 m and 30 × 30 m of the territory, were processed. The results indicate that the Pina oilfield anomalous complex is recognized, at least, in four other new localities, although with less areal extension; one of them is the Paraíso sector. Other deposits and prospects such as Brujo, Ceballos, and Pina Sur have anomalous complexes similar to Pina's, but incomplete in some of their attributes. The same happens for other established interest sectors. From the use of the ***Redox Complex***, the presence of hydrocarbons in the depth was established in different sectors with anomalous indicator complexes, many of them coinciding with seismic structures. These sectors are, in Ciego de Ávila: Pina Sur, Pina Sur SO, Oeste de Ceballos 1, Oeste de Ceballos 2 and Pina Oeste Norte, and; in Sancti Spíritus, Gálata 2.

A version of the geo-structural mapping of the Habana–Matanzas (Block 7) region, based on the gravitational–magnetic data and, the mapping of sectors of gasopetroliferous interest linked to the conventional oil of the Placetas Tectonic-Stratigraphic Unit, is offered, based on the presence of a complex of indicator anomalies. The source materials were the same used for the previous region. Besides, a results' map of remote sensing for the search of perspective gasopetroliferous sectors in the region of Guanabo–Seboruco was used. The processing consisted in the regional-residual separation of the gravimetric and morphometric fields, the calculation of the first vertical derivative of the gravimetric and aeromagnetic fields, the inclination derivative of the reduced to pole magnetic field and of the ratio K/Th spectrometry channels. The indicator anomalous complex considers the following attributes: low-amplitude local gravimetric maxima; minimum of K/Th ratio and local maximums of U (Ra) at its periphery; local maximums of residual relief and remote sensing anomalies. As a result of the geo-structural

mapping from the gravimagnetic data, a wide distribution of the Zaza Terrain (volcanic + ophiolites) was observed in the study region. The main structural depressions are concentrated along a latitudinal strip that covers the following locations (from east to west): Southwest of Matanzas Bay, Ceiba Mocha, Aguacate, Bainoa, Tapaste, Cuatro Caminos, Managua, and Santiago de Las Vegas. Based on estimates of the reduced to pole magnetic field, the depth at the top of a target located to the west of Bainoa, within the mentioned strip, was 1350–1450 m, which gives an idea of the basin's sedimentary thickness. The results of the integrated prospective cartography at the study region consider, in the first level of perspective, three localities (Boca de Jaruco, Jibacoa del Norte, and Este de Aguacate) where all the studied anomalies (attributes), with the exception of the morphometric ones, appear. In the second level of perspective, the localities that correspond to the combination of two types of different anomalies (11 localities) were considered.

Another geological task posed to the geological–geophysical processing and interpretation consisted in the mapping of possible new gaso-petroleum targets that will base the exploration at two regions in the western (Block 9) and central (Block 13) Cuba. The source materials and the processing were the same than the previous regions, with the exception of the remote sensing anomalies. As result, the mapping of sectors of oil–gas interest in western and central Cuba, related to the conventional oil of the Placetas Tectonic-Stratigraphic Unit and the Jurassic level, was based on the presence of a complex of indicator anomalies. It considers the following attributes: subtle local gravimetric maximum (in or near regional minimum); minimum of the K/Th ratio and local maximum of U (Ra) at its periphery, and; maximum of residual relief.

The last scenario of study includes the seas to the south of Cuba: shallow, transitional, and deep waters, characterized by the Batabanó, Ana María, and Guacanayabo gulfs, parts of the Yucatan Basin, the Cayman Ridge, and the Cayman Trench (on the edge of the Bartlett Fault). For this territory, with a low degree of seismic study, it was very important to count on other complementary non-seismic exploratory tools, like Digital Elevation Models, that allowed a preliminary assessment of the prospective areas. Then, the geological task posed to the morphometric processing and interpretation consists of the morphotectonic regionalization, with precision of the morpho-structural evidence of the so-called "Camagüey Trench" and, the establishment of possible sectors of oil and gas interest linked to the presence of geomorphic anomalies, presumably Indicators. For such purposes, the Digital Elevation Model 90 × 90 m was processed. As a result, the Morphotectonic Regionalization of the South Cuba marine territory was carried out, recognizing three types of regions: shallow waters (less than 100 m), transitional waters (greater than 100 and less than 3000 m), and deep waters (greater than 3000 m), from which could be characterized the different physiographic features already known. According to the interpretation, the existence of obvious signs of a

trench and, therefore, of a paleo-subduction zone in southern Cuba is not recognized. Taking into account the range of amplitude of the geomorphic anomalies, if there is an active petroleum system, the areas of greatest prospective interest would correspond to the three gulfs (shallow waters) and, to the southwest and south of Batabanó Gulf and the northern limit of Cayman Ridge (transitional waters). The anomalies in deep water are vetoed by the huge water strain.

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Contents