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High-resolution seismic stratigraphy of the late Neogene of the central sector of the Colombian Pacific continental shelf: A seismic expression of an active continental margin

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A B S T R A C T

The sedimentary prism of the central Pacific continental shelf of Colombia was affected by regional folding and faulting, and probably later mud diapirism, from the Late Miocene to the Holocene. Interpretation of high-resolution seismic lines (2 s/dt) revealed that the prism consists of 13 high-resolution seismic units, that can be separated into 5 seismic groups.

Deposition of the prism and the associated stacking pattern, are probably the response to variable uplift and subsidence in a fore-arc basin that underwent important tectonic events by the end of the Miocene. Throughout the Pliocene, the continental shelf sedimentation was affected by the growing of a dome structure probable due to mud diapirism. This fact caused peripheral faults both normal and reverse that controlled the distribution of some of the seismic units. During the Late Pleistocene (Wisconsin stage?) a eustatic sea level fall caused the shoreline to advance about 50 km westward of its present position. Because of this eustatic sea level change, a strong fluvial dissection took place and is interpreted as the probable extension of the San Juan River to the south of the present day river mouth. Within this framework it is believed that the Malaga and Buenaventura Bays were the passageways of branches of the old drainage system of the San Juan River. The inner branch circulated through the present Buenaventura Bay and runs southward leaving the mark of an apparent valley identified in the seismic information in the eastern sector of the study area. This old fluvial valley and its filling material located in the present day inner continental shelf front of Buenaventura are postulated as important targets to find placer minerals such as gold and platinum.

R E S U M E N

Un prisma sedimentario en el que se involucran ambientes de talud continental, plataforma continental, y depósitos de playa fue afectado por plegamiento y fallamiento regional y más tarde por un probable diapirismo de lodo desde finales del Mioceno hasta el Holoceno. Su ocurrencia se da en la parte media de la plataforma continental del Pacífico de Colombia. Mediante la interpretación de líneas sísmicas de alta resolución (2 seg/td) se logró la identificación de 13 unidades sísmicas que pueden separarse en 5 grupos sísmicos.

El depósito de unidades sísmicas y sus patrones de apilamiento son probablemente respuesta a tasas variables de levantamiento y subsidencia en una cuenca de antearco que experimentó pulsos tectónicos importantes a finales del Mioceno. Durante el Plioceno la sedimentación de la plataforma continental fue afectada por el desarrollo de una estructura dómica probablemente asociada a diapirismo de lodo, el cual produjo el desarrollo de fallas periféricas normales e inversas que ejercieron control en la distribución de algunas de las unidades sísmicas. Durante el Pleistoceno tardío (Wisconsiniano?) ocurrió un descenso eustático del nivel del mar produciendo un avance de la línea de costa de cerca de 50 km, hacia el oeste de su posición actual. Como consecuencia de ese cambio eustático del nivel del mar, ocurrió una fuerte disección fluvial, la cual es interpretada como la probable extensión del cauce hacia el sur de la actual desembocadura del Río San Juan. Dentro de este modelo se considera que las bahías de Málaga y Buenaventura fueron

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conductos de tributarios del antiguo drenaje del Río San Juan. El tributario más interno se desplazó por la actual bahía de Buenaventura y se proyectó hacia el sur, dejando a manera de huella, un antiguo valle el cual es identificado en la información sísmica, en el sector oriental de la zona de estudio. Este antiguo valle fluvial y su material de relleno localizado en la actual plataforma continental interna, frente a Buenaventura, se considera un blanco importante en la prospección de minerales de placer, tales como oro y platino.

1. Introduction

The structural knowledge of the continental margin of the Colombian Pacific is presented in different research studies of the Panama Basin, among which can be mentioned Case et al. (1969), Lonsdale and Klitgord (1978), Pennington (1981), Duque-Caro (1990), Hardy (1991), Kellogg and Vega (1995), Meschede and Barckhausen (2000). These studies have in common their focusing to the understanding of the Nazca Plate and the South American Plate interaction during the Paleogene and Neogene.

These studies indicate that the platform and the continental slope in the Colombian Pacific was the result of the structural evolution of an accretion prism that controlled the sedimentary basin development, parallel to the present shoreline. It is important to emphasize that there are no studies on the Neogene based in high-resolution seismic profiles on the continental shelf of the Colombian Pacific. It was this fact that encourages us to undertake a stratigraphic seismic analysis of the continental margin of the Colombian Pacific. The stratigraphic patterns of high-resolution sequences developed in an active converging margin, are herein described in detail.

Given the limited access to well information and their poor quality, this study was not focused in the chronostratigraphic component. However, the study was oriented to identify the variations in geometry, stacking patterns, and seismic units distribution, resulting from the tectonic events and the global eustatic changes, that affected the continental margin of the Colombian Pacific area, from the Upper Miocene to Holocene times. As a result of this study, it was possible to detect the existence of sedimentary sequences affected by tectonic events influenced by apparent mud diapirism and global eustatic changes, from the end of Miocene until the Holocene.

2. Data sources and methods

The study area, located in the central continental margin of the Colombian Pacific area, is bounded to the north by Buenaventura Bay, to the south and east by the coast line fronting the Naya River and to the west by the continental shelf break (Fig. 1). The area encompasses approximately 4200 km^2. The Central Pacific continental shelf, in front of the Buenaventura Bay, is relatively wide, attaining 65 km. To the south the width gradually diminishes attaining only 20 km. Consistently with the width change of the platform its slope gradient varies from a slope of $0°15'$ to the north increasing towards the south to $0°19'$ (Based on CIOH, 1999). This topographic change characterize entirely the study area, except the outer platform, where incisions affect the continental slope, some of them seem to be the extension of large rivers of the Pacific Coast.

The continental shelf break, can be defined by the 200 m bathymetric line. To the west of this line, begins the continental slope, whose gradient varies from 4° in the northern part to 3° in the southern part. The west limit of the continental slope, is defined by the slope change that occurs with the oceanic trench, at a depth of approximately 3500 m, namely the Colombian trench (Fig. 1). From the hydrographic point of view the study area is dominated by tides, which can be catalogued as mesotides (3.5 m), according to Martínez et al. (1995) and González et al. (1998). The effect of the tide domain toward the interior of the continental shelf is evidenced by wide tide deltas, emerging from the main river mouths in the shore and extending, in some cases, for more than 3 km seaward.

Forty kilometers of high-resolution (2 s/dt) reflection seismic lines were interpreted. These seismic lines were acquired by ECOPETROL, during the hydrocarbon exploration of the decade of the 70s (Fig. 2). The high-resolution reflection seismic data allowed the seismic stratigraphic analysis of bodies with thickness over 20 m, and the definition of the relation between the different seismic units, their geometry, and their stacking patterns.

In addition, 140 km of deep penetrating (5 s/dt) multichannel reflection seismic profiles shot during the 80s by hydrocarbon exploration companies and compiled and interpreted by GEOTEC (1997) were evaluated. This information was examined with the purpose of mapping the structures and major sedimentary sequences that characterize the area. During the development of this work, a new geophysical acquisition projects have been realized in the area, but they could not be integrated because is a confidential information.

The seismic reflection data used in this study were correlated with subsurface information from nearby deep exploratory well Tambora-1. The Tambora-1 well was directly tied to the seismic lines 00B and 014 and provided geologic control for identifying some seismic units. This well also was analyzed through the time-velocity curve (Fig. 3) in order to adjust the velocities of the different seismic units. The exploratory well Tambora-1, is located in the northern central part of the area (Fig. 2), and geologically is located on a structural high. As result of the analysis of the time-velocity curve, three main velocity intervals were defined (Fig. 3). The more recent groups of seismic units (Groups 3–5) show an average velocity of 1650 m/s. This value is similar to the acoustic velocity used for recent sediments by Morton and Suter (1996) and Lehner (1969) in other parts of the world. For intermediate seismic units (Group 2) was used an average velocity of 1800 m/s. A larger velocity value close to 2600 m/s, was used for the older group of seismic units (Group 1). The correlation of seismic sequence boundaries between lithological descriptions of the Tambora-1 well with stratigraphic interpretations of geological units onshore by Nivia (2001), was used to place in time the seismic groups boundaries defined in this study.

The basic concepts and the terminology used in this study follow the guidelines and working methodologies of Sheriff (1980), Vail (1987) and Vail et al. (1991), for the seismic stratigraphic analysis of sedimentary basins. The basic techniques are based on the definition of boundary surfaces between sequences or seismic reflection groups. The group of seismic reflections defined by boundary surfaces was formed during a geological time interval given by the age of its boundaries. The time interval during which a group of seismic reflections was deposited varies from one place to another if the boundary surfaces are unconformable. If the boundary surfaces are conformable, the time interval during which a group of seismic reflections was deposited is the same. The boundary surfaces are defined based on seismic reflection patterns of different type such as truncation, onlap, downlap and toplap. The