SUBSIDENCE AND CRUSTAL FLEXURE EVOLUTION OF THE NEOGENE CHACO FORELAND BASIN (BOLIVIA)

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RÉSUMÉ: L'évolution de la subsidence dans le bassin du Chaco (Bolivie) est étudiée à l'aide de sismique réflexion, de gravimétrie et de diagraphies différées. Les courbes de subsidence depuis le Miocène supérieur mettent en évidence trois étapes tectoniques avec des taux de subsidence compris entre 0,1 et 0,4 km/Ma. L'application d'un modèle de flexion, avec une rigidité de flexion de 10^{23} N.m et une épaisseur de la croûte de 30-31 km, permet de décrire l'évolution de la géométrie et de la topographie du bassin depuis 10 Ma.

KEY WORDS: Bolivia, foreland basin, crustal flexure, tectonic subsidence, geophysics, model.

INTRODUCTION AND GEOLOGICAL SETTING

During the last decade, important progress has been made in understanding the subsidence mechanisms of foreland basins. Several modelling studies in continental regions have shown that the flexural response to tectonic loading can be represented by an elastic plate overlying a weak fluid (Turcotte and Schubert, 1982; Flemings and Jordan, 1989). The purpose of this paper is to quantitatively estimate the evolution of tectonic subsidence and crustal flexure in the Chaco basin of Bolivia (lat 19°-20°S) through study of geological, seismic reflexion, gravity and log-welling data (mostly unpublished and borrowed from the Bolivian State Oil Company YPFB).

The study was carried out in the Subandean belt of southern Bolivia (Río Grande-Parapetí area; lat 19°-20°S and long 62°-63°S; Fig. 1). The Subandean belt is bounded in the west by the Main Frontal Thrust (CFP, "Cabalgamiento Frontal Principal"), and the Subandean deformation dies out toward the east into the Chaco plain (Hérail et al., 1990; Baby et al., 1992). During the Neogene, the width of the foreland basin has apparently varied from 100 to 120 km in general. The basin is filled by late Oligocene to recent sediments (Sempere et al., 1990) with a maximum thickness of 3000 m in the study area. The Tertiary deposits consist of conglomerates, sandstones, siltstones and mudstones, and are subdivided in the Petaca, Yecua, Tariquía, Guandacay and Emborozú formations (see Marshall and Sempere, 1991; Marshall et al., 1993).

RESULTS

Wireline data and cutting descriptions from two wells (further on referred to as well 1 and well 2) were used to build the two corresponding synthetic stratigraphic columns. Structural maps and seismic reflexion lines, in which four Tertiary sequences — bounded by reflectors T_1, T_2, T_3 and T_4 — were selected, were interpreted and correlated with these two logs (Fig. 2). Ages tentatively attributed to these reflectors are respectively: $T_4 \approx 10$ Ma (beginning of local onlap of Neogene deposition), $T_3 \approx 7.5$ Ma (top of Yecua Formation; see Marshall et al., 1993), $T_2 \approx 4.5$ Ma (by interpolation), $T_1 \approx 1$ Ma (major out-of-sequence reactivation of the CFP system; Sempere, unpublished). Future precisions on the ages of these reflectors may obviously lead to modifications of some of the results presented hereafter.

In order to approach the effects of subsidence, the "back-stripping" method (Steckler and Watts, 1978) was used. The effect of compaction was incorporated for computation of tectonic subsidence. Paleobathymetry and sea-level changes were neglected because the depositional environment remained fluvial.

The porosity of argillaceous sands and mudstones as a function of depth was deduced from sonic tool (BHC) and density tool (FDC) using the matrix parameters and assuming a linear relation between porosity and well logs (Steckler and Watts, 1978).

Three stages were identified (Fig. 3). During stage T_4-T_3 (≈10-≈7.5 Ma), the tectonic subsidence rate was ≈0.4 km/Myr. During stage T_3-T_1 (≈7.5-≈1 Ma), this rate decreased to ≈0.1 km/Myr. Stage T_1-T_0 (from ≈1 Ma to the present) apparently shows an increase in subsidence rate to ≈0.4 km/Myr (Coudert, 1992).

The Bouguer anomaly regularly increases toward the east, i.e. toward the "Alto de Izozog" forebulge (YPFB, unpublished data). In order to understand the distribution of the successive loads on the continental lithosphere, the power spectrum of gravity anomalies (Karner and Watts, 1983) was determined. Discontinuities evidenced through this method are located at the top of and within the basement, i.e. below the base of the sedimentary pile (2-2.2 km-thick). The deepest discontinuity, at 31-32 km, apparently corresponds to the Moho. This crustal thickness is used for estimation of the flexural rigidity, which appears to be ≈10^{23} N.m (Coudert, 1992).

The evolution of crustal flexure using an elastic model (Turcotte and Schubert, 1982; Flemings and Jordan, 1989) is shown in Fig. 4. The best fit between computational results and seismic and well data is obtained when a flexural parameter (≈horizontal extension of the flexure) of ≈70 km is chosen.

In addition, the position (x_b) and height (w_b) of the forebulge were estimated for each period (Fig. 4). A migration of the forebulge of about 90 km is observed for the last ≈7.5 Myr, which indicates an average migration velocity of ≈9-10 km/Myr.

CONCLUSIONS

Analysis of multiple geophysical data in the late Miocene Chaco continental foreland basin of Bolivia permits to sketch out its evolution and to tentatively describe its successive geometries and topographies since 10 Ma. At least three tectonic stages are identified, which include an interval of relatively low subsidence (≈0.1 km/Myr; ≈7.5-≈1 Ma) intercalated between intervals of higher subsidence (≈0.4 km/Myr). Models used agree with a flexural rigidity of ≈10^{23} N.m and a crustal thickness of ≈30-31 km.

Acknowledgments

This work was funded by the French Research Administration, the Institut Français de Recherche Scientifique pour le Développement en Coopération (Orstom), and Yacimientos Petrolíferos Fiscales Bolivianos (YPFB). We thank the Gerencia de Exploración of YPFB for granting permission to publish this paper.

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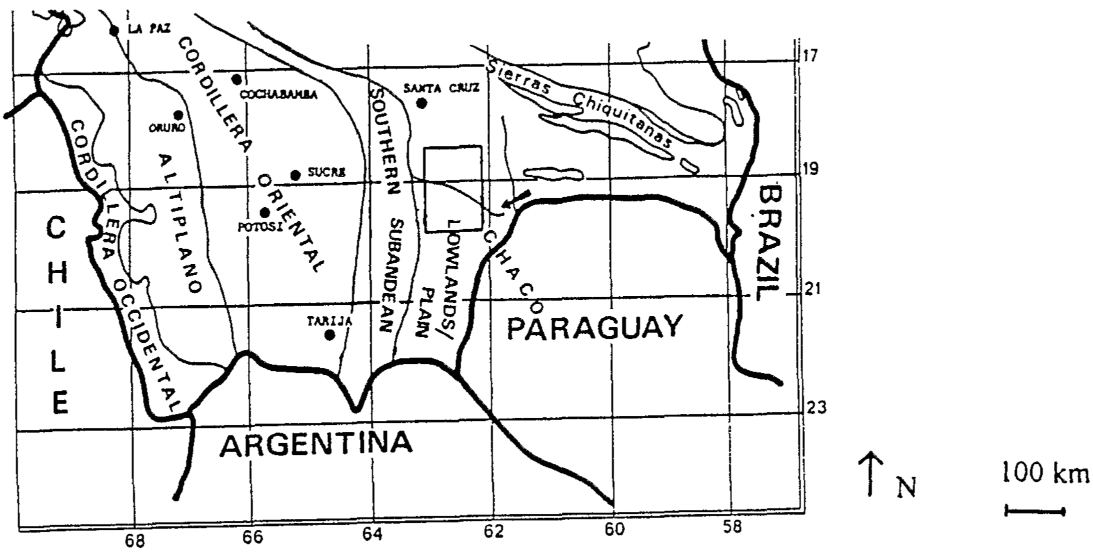

Fig. 1 — Map of southern Bolivia showing location of studied area.

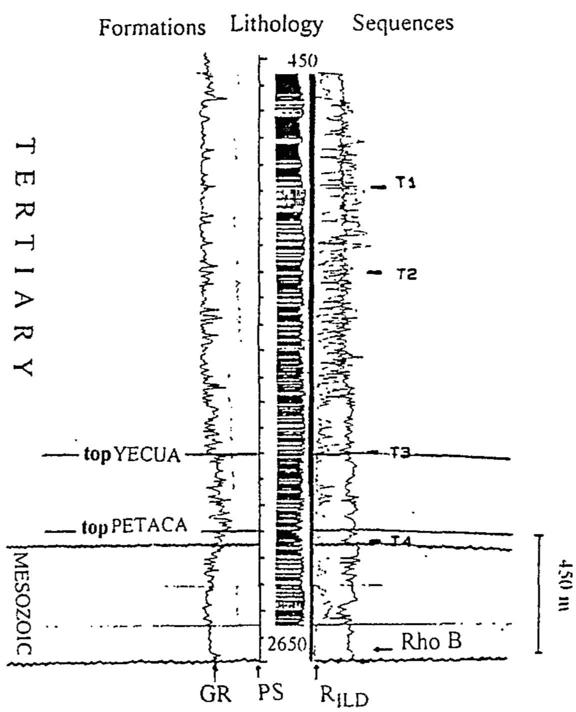

Fig. 2 — Schematic lithology and stratigraphy of well 1, with indication of stratigraphic location of reflectors T_1 through T_4. Wireline logs: GR = gamma ray, PS = spontaneous potential, R_{ILD} = induction resistivity, Rho B = density tool (FDC). Lithology: sandstones are in white; mudstones are in black.

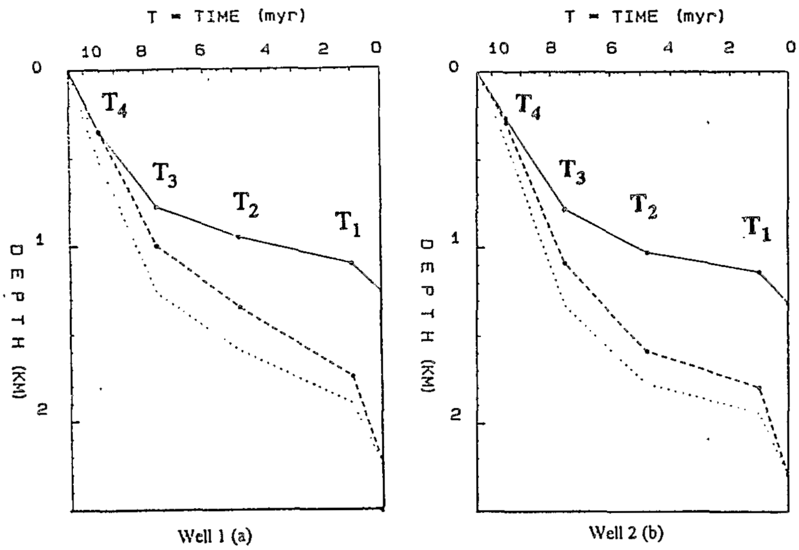

Fig. 3 — Tectonic subsidence curves since 10 Ma for wells 1 and 2. Dashed line: observed subsidence; dotted line: subsidence after decompaction; solid line: computed basement subsidence.

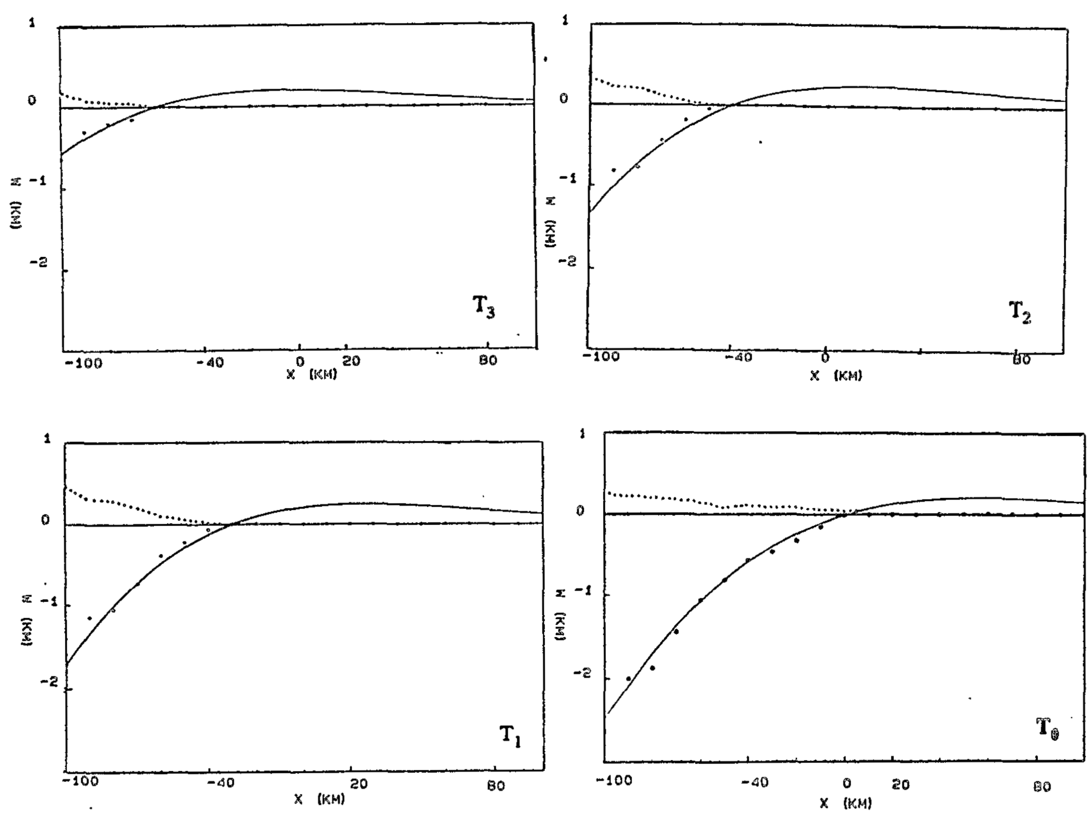

Fig. 4 — Successive depths of the top of the basement at "times" T_3, T_2, T_1, and "T_0" (present). Points: observed seismic data; solid line: computed flexure profile; dotted line: compensated topography.