Petroleum Potential of the Bolivian Altiplano

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Introduction:

Petroleum exploration in the Bolivian Altiplano has been active in the 70's years without any commercial success and started again in 95 with three wells drilled by YPFB and EXXON. This new phase began with a complete re-evaluation of the zone based on seismic interpretation and field studies. A more coherent structural interpretation has been proposed and the source rocks content has been quantified. We will present here an evaluation of the petroleum potential of Altiplano based of the structural sketch proposed by the YPFB's geologists and the ORSTOM's ones P. Baby and Ph Rochat (Univ. of Grenoble)

Source rock:

The two main source rocks on the Bolivian Altiplano are the Paleozoic (Silurian + Devonian) and the Upper Cretaceous (Chaunaca Fm, Santanian, and El Molino Fm., Maastrichtian to Danian).
The Lower Paleozoic contains some rich organic levels. It is overmature in the Eastern Cordillera as well as in the Sub Andean Zone, but may eventually play some role on the western part of the Altiplano, where the Middle to Upper Paleozoic is supposed to have been thinner, or missing as in the San Andres well. The Middle Paleozoic is the main source rock on the Sub Andean Zone (Moretti et al., 1994, Fig 1) and, at least in the Eastern part of the Altiplano, shows similar facies to the ones known on the Sub Andean Zone (Moretti et Aranibar, 1995). It is a marine source rock with a rather low but constant petroleum potential (Initial S1+S2 around 5 mg HC/g, Fig 2). The main dubiousness concerning the influence of this source rock is its thickness in the Altiplano. The Silurian and Devonian reach a total thickness of up to 4000 meters on the Sub Andean Zone, as opposed to the Altiplano, which may correspond more or less to the western border of the Silurian-Devonian foreland basin. Southward, from the Uyuni-Kheuany faults, the Devonian is missing
The Permian and Carboniferous are present in the north, around the Titicaca Lake, but are missing in the south due to pre-Jurassic erosion (Diaz, 1994). The Lower Carboniferous is characterised by a progradational deltaic sequence and does not present a high potential except very locally. The Upper Carboniferous and Lower Permian Copacabana Fm. is an excellent source rock on the northern part of the Sub Andean Zone (Lliquimuni area, Moretti et al., 1994) and, by reputation, it is the source rock of the Pirín field in Peru, but organically rich and thick facies have not been recognized in the Bolivian Altiplano area, where the Copacabana Fm. is mainly calcareous.
The El Molino Fm. could locally present very high potential (S2 up to 20 mg HC/g, Aranibar et al., 1995), but the data are rather inhomegeneous. The best values are from the Eastern Cordillera, where the Cretaceous is immature (Fig 1). On the Altiplano, Cretaceous outcrops are numerous on the eastern part and lead to various debates in terms of depositionnal environment (Gayet et al., 1993, Blanc-Valleron et al., 1994). Westward, only the Tertiary is outcropping, and a lot of uncertainties remain on the facies and even on the units existing on subsurface, the existence of an Ordovician source rock as well as some Jurassic ones, related to the Chilean back arc opening, is not to preclude but remains hypothetical.

Tectonic setting

The Pacific subduction started in early Mesozoic times, first in an extensional context (various backarc basins may be recognized from Jurassic to Cretaceous over the whole margin from Venezuela to south Chile, and then in a compressional context (Jaillard, 1994). The change from extension to compression is not synchronous along the margin, and in Bolivia is late compared with neighboring regions. The Cretaceous is still extensional and the Paleogene is characterized by large and deep half grabens which may correspond to strike-slip faults. The first definitively inverse faulting started at the end of the Oligocene (27 My, Sempere et al., 1990), with thrusting and uplift in the modern Eastern Cordillera. Nevertheless the compression may have started before late Oligocene (Butler et al., 1995). Late Oligocene also corresponds to the formation of the Altiplano as an isolated basin, limited to the east by the Eastern Cordillera and to the west by the Western Cordillera, formed by the Andean volcanoes. The erosion of the Eastern Cordillera induced conglomeratic deposits along the east (Coniri Fm.) when the western part is mainly volcano-detritic. The previously formed half grabens were then progressively inverted on the Altiplano and subsidence continued in some basins. This phase of compression took place at the end of the Miocene, and is contemporaneous with the eastward migration of the compressional front of the Sub Andean Zone, where the thrusts are dated from 14 Ma to recent (Baby, 1995). The current phase starting in the Pliocene is also compressive (Baby et al., 1990, 1992), and leads to the uplift and strong erosion of the eastern part of the Altiplano (Geise, 1994). The very rapid vertical movements which started presumably at the Upper Miocene, are due to deep processes: crustal thickening (James, 1971) and lithospheric thinning (Wigger, 1993) and are accommodated by high-angle faults.

Thermicity:

The current heat flow is very high, the average value reaches 100 mW/m^2 (Henry et Pollack, 1988). These data are compatible with the already mentioned lithospheric thinning and lead to a shallow oil window (around 2500 meters). One may correlate this heat flow to the present desequilibrium (-400 mgal on the Bouguer gravity anomaly) and uplift of the area. We suggest to date the increase from a normal heat flow (around 60 mW/m2) to 100 mW/m^2 at the Upper Miocene coeval with the increase of uplift rate in the area.

Timing of HC generation and migration

Supposing that the Middle Paleozoic source rock did not mature during the Late Paleozoic, the generation of HC from both Paleozoic and Cretaceous source rocks started in the Oligocene, at the end of the Potoco-Tihuanacu deposits, and it is mainly active during Miocene time. The speculated reservoirs are Cretaceous to early Tertiary, so the traps are all connected to the Neogene evolution of the area. Recent structures (end of Miocene to present) are risky because they are more recent than the increase of subsidence. One of the main risk, is also the lack of reservoir, for instance the Toledo-X1 well drilled by EXXON in the northern part of the Poopo lake found the Paleozoic below the Miocene without proving any reservoirs since the Cretaceous and Paleogene were missing due to erosion at the top of the structure.

Current exploration:

The Altiplano is a frontier zone where only 8 wells have been drilled, 5 between 1970 and 1976 and 3 between 1995 and 96. Three of them were badly located (salt domes or basement structures). The southern one (Vilque) was drilled on a Paleozoic high and showed that the Cretaceous is very thin and not organically rich in this part. Large quantities of methane and nitrogen have been reported. The methane seems to indicate the presence of an overmature source rock, and the nitrogen has not been explained. The northern well, San Andrés de Machaca, is also dry and does not record any source rock potential. The Precambrian basement has been found directly under a sandy Cretaceous leading to very negative conclusions for the northern western part of Altiplano. The oil seeps are all on the eastern part, except the Rio Mauri one. The origin of each one is still a matter of debate.

Conclusions

From a structural point of view, the Altiplano may be divided in two parts. The eastern part is thursted by the Eastern Cordillera and affected by strong compressional features. The western part is characterized by Early Tertiary deep half-grabens that may still be recognized and have been slightly inverted during the Miocene. Eastward, many of the structures involved evaporites from the Cretaceous and Early Paleogene, as can be seen on outcrops and in numerous seismic lines.

From a geochemical point of view, the eastern part is rather well known: the Paleozoic source rocks exist from north to south (to the Uyuni-Khenayani Fault) and the Cretaceous (El Molino Fm. & Chaunaca Fm.) presents an excellent potential. Nevertheless, the Chaunaca Fm. is too thin (5 meters of source rock) for an active participation to the petroleum system, and the true thickness of source rock in the El Molino Fm. is still poorly known (from 30 to 100 meters). To the north, the Permian and Carboniferous source rocks are present, but are also very thin, and the outcropping Cretaceous does not show any high HC potential. To the south, the same fact has been recorded, the El Molino Fm. reduces its potential and becomes thinner and more sandy. Eastward everything is speculative and there is no proven source rock. Hopefully, a new well in this part will allow a better knowledge of the area on the coming months.

From a timing point of view, the best structures are the oldest ones, and this means the highest part of the Early Paleogene halfgrabens (as Santa Lucía to the west), or the first compressive one related to the Late Oligocene phase (they are numerous on the Poopo Lake area).

This study has been done through the YPFB-ORSTOM convention. The data comes from the YPFB-GXG data base and some additional samples has been collected during field studies made with the TOTAL geologists J.L. Pittion and M. Specht. We thanks the YPFB colleagues (J. Jarandilla, E. Martínez y G. Navarro) for many helpfull discussions and the YPFB exploration managment, Ings. M. Cirbián y M. López, for help and autorization to publish.

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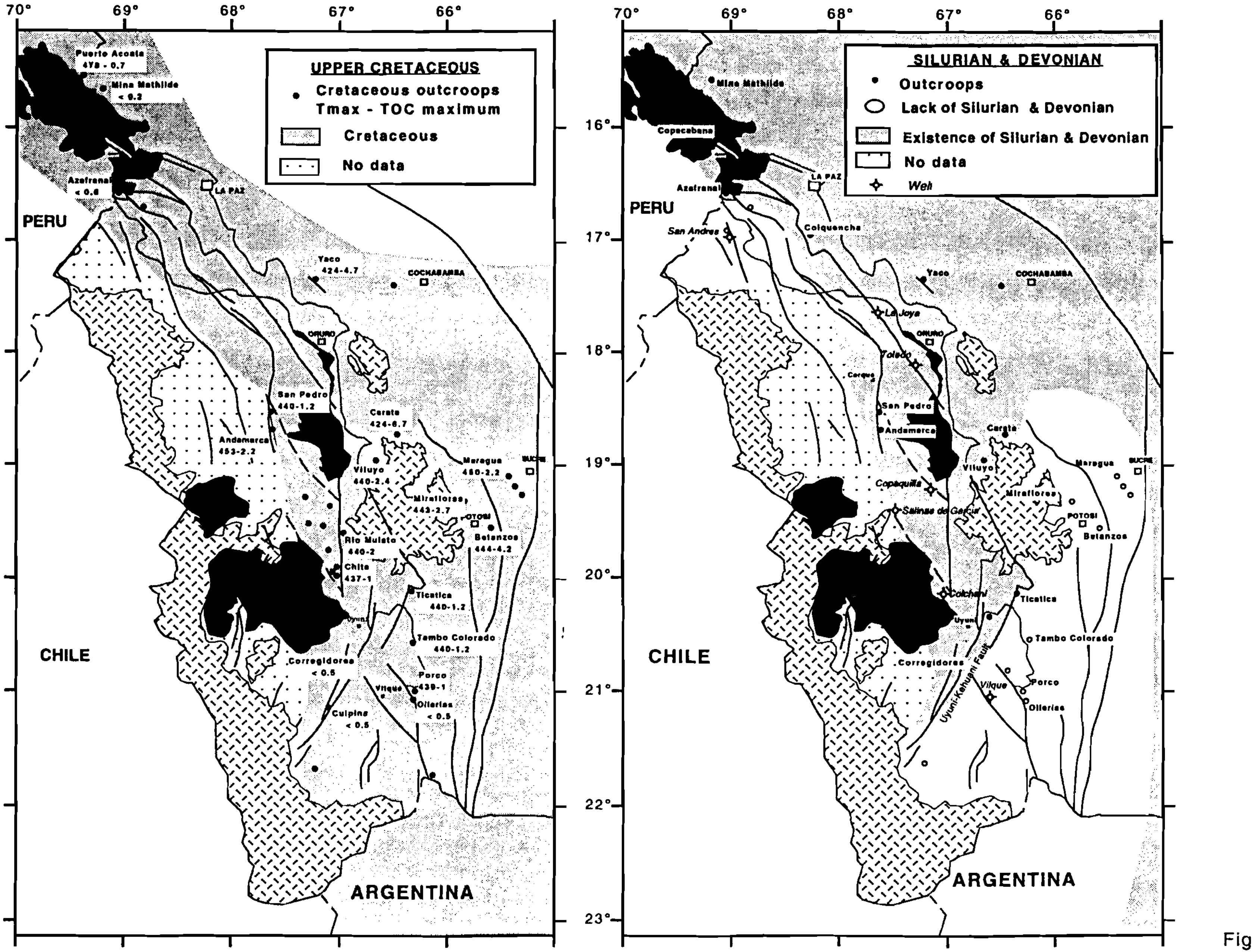

Fig 1

Third ISAG, St Malo (France), 17-19/9/1996