THE TUPIZA, NAZARENO AND ESTARCA BASINS (BOLIVIA): STRIKE-SLIP FAULTING AND THRUSTING DURING THE CENOZOIC EVOLUTION OF THE SOUTHERN BRANCH OF THE BOLIVIAN OROCLINE

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RESUME: Des bassins de Tupiza, Estarca et Nazareno (sud de la Bolivie) le plus ancien d'entre eux (celui de Tupiza) s'est ouvert aux environs de 23 Ma sur une zone en décrochement senestre orientée N-S. Ce n'est qu'à partir de 20 Ma environ que l'évolution tectonique et sédimentaire a été controlée par des chevauchements N-S. Ces mouvements se sont fortement ralentis vers 10 Ma permettant le développement de topographies d'aplanissement étendues (Surface San Juan de Oro).

KEY WORDS: Cenozoic basin, thrusting , strike-slip, Bolivia.

INTRODUCTION.

During the Cenozoic, the tectonic structuration of the Bolivian Andes has been adquired through thrusts. This tectonics is responsible for an important amount of shortening (Sempere et al., 1990; Sheffels, 1990). Before these thrustings took place, left-lateral transcurrent deformation is documented in the southern part of the Bolivian Altiplano (Baby et al. 1990) but, generally speaking, it is impossible to analyse with much detail these movements and their chronology. In the Tupiza region the sedimentary rocks and deformational features formed under the influence of changing stress conditions are well exposed and their chronology can be constrained.

REGIONAL SETTING.

The Tupiza basin is 6 to 13 km wide and extends over 80 km in a N-S direction, parallel to the Aiquille-Tupiza Fault, and continues towards the South in Argentina. The bottom of the valley that drains it at present, is located at around 2800 m above sea level and is surrounded by highlands reaching 4000-4200m. These highlands are made of Early to Mid-Ordovician rocks and are cut by remains of well-preserved erosion surfaces (Servant et al., 1989): the Chayanta Surface (above 4000m high) and the San Juan de Oro Surface (≈3500-3800m). On the western side, a highland separates the Tupiza basin from the Estarca basin which extends N-S over 70 km and is 6 to 12 km wide. Towards the east, another highland separates the Tupiza basin from the Nazareno basin which extends in a N-S direction over 80 km. Towards the south, the Nazareno basin and the Estarca basin gradually lead to flat regions: Chaupi Yacu (3500m) and Livia Pampa (3800m) respectively that correspond to the San Juan de Oro Surface. In contrast, north of the three mentioned basins, San Juan de Oro Surface remnants (Mochara Pampa) are exposed at an altitude of ≈ 3500 m, at 500 m above the bottom of the present valleys.

THE SEDIMENTARY INFILL

The Cenozoic sediments of the Tupiza basin have a continental origin. Conglomeratic facies constitute the bulk of the basin infill with minor sands, clays, sometimes gypsiferous clays, and less commonly carbonate deposits. The sedimentary pile is discordant on the top of the Ordovician, which in turn is composed essentially of black pelites (Cieneguillas Fm and Obispo Fm).

The sedimentary infill starts with the deposition of red breccias (frequently affected by synsedimentary normal faults) composed of Ordovician rock fragments and clays. Locally, in the deepest parts of the basin (Palquiza and Quebrada Catati area) a more complete sequence is preserved which, in addition to the basal breccias, contains around 50 cm thick layers of well-sorted sands with ripples or cross bedded channels. To the top, these sandy sediments change laterally into either scarce lacustrine deposits or into flood plains sediments in a evaporitic environment (greenish, violaceous and sometimes reddish clays whith gypsum veinlets, gypsum and halite layers that can reach 50 cm thick, and scarce beds of limestones with fish-teeth and gasteropods-shells). This formation (Catati Fm) is around 50 m thick.

The Catati Fm is overlaid by a thick accumulation of red, coarse-grained conglomerates (Tupiza Fm - Montaño, 1966) which outstands in the landscape of the basin These matrix-supported conglomerates, organized in fluvial to fluviotorrencial channels with normal graded bedding, are essentially composed of pebbles and boulders of Ordovician rocks, the diameter of which may exceed 50 cm. In addition, they locally contain Cenozoic lava clasts, Mesozoic sandstone and Pucalithus limestone fragments preoceeding from the El Molino Fm (Maastrichtian) which does not crop out in the surrounding area of the basin at present. The matrix is often very abundant and interbedded mudflows are numerous. In the lowest part of the Catati Fm., lava flows crop out (Cerro Bolivar, along the way Tupiza-Mochara, on the foothills from the Cerro Cruz to the Cerro Chaupiloma). Due to their alkaline feature, we assimilate them to the lava flows of the Rondal Fm. (see Soler and Jimenez, this volume). Clasts of these lavas flows are frequent in the conglomerates of the Tupiza Fm, but they are scarce in the brccias of the Catati Fm.

The Nazareno Fm overlies the Tupiza Fm. Generally, a reverse fault juxtaposes both formations; in some spots of the central part of the basin however (Quebrada Catati, Quebrada Checona) the stratigraphic, unconformable contact between them is observed. In the Nazareno basin, the Nazareno Fm starts with a deposit of subangular conglomerate the clasts of which come from the Ordovician (some 10 m thick only) The conglomerates are overlaid by argillaceous and sandy layers interbedded with either conglomerates or dacitic pyroclastics. The same pink-coloured facies with clasts from volcanic origin (dacite) and scarce ash-beds crop out widely in the Tupiza basin. Moreover, the conglomerates of the base of the Nazareno Formation often contain reworked fragments of the underlaying Tupiza Formation sediments.

The sediments of the Estarca basin are contemporaneous with the Nazareno Fm. These conglomerates are made of Ordovician fragments. The basin infill corresponds to only one sedimentary wedge. To the eastern side of the basin the series is thicker (1000 to 1500m) than towards the west, and the alluvial fan conglomeratic facies prevail. These conglomerates come from the east. On the western side of the basin, the sedimentary infill is thinner and overlaps progressively the Ordovician strata. On this side the sediments are formed by Ordovician subangular fragments which were deposited by a sheet flood. These sediments come from the west. To the center of the Estarca basin both these sediments and those coming from the east are interbedded with flood plain fine-grained deposits.

The Oploca Fm (Montaño, 1966) overlies by progressive unconformity the Nazareno Fm, or by an unconformity the Ordovician basement. The light brown Opoca Fm is composed of fluvial conglomerates containing well rounded pebbles. Sometimes the sandy matrix is very abundant. Volcanic clasts (essentially of dacitic composition) are abundant, and volcanic tuff levels, generally reworked, are exceptionally found. The strata, generally from one to several meters thick, are very continuous. The gradded-bedding is normal. Measurements of paleoflow directions show that these fluvial sediments were transported by streams flowing according to the basin orientation; in contrast, in the older formations, flow directions predominantly went from the edges towards the center of the basin. The transition between the Nazareno Fm and the Oploca Fm does not show a sharp change in the composition of the sediments, only the coarse fraction becomes more abundant.

In the Tupiza Fm, a sample of an alkaline lava flow of the Cerro Bolivar gave a K/Ar whole rock age of 22.7±0.6 Ma. In the Nazareno Fm two biotite K/Ar ages yielded 20.0±0.6 Ma (Cerro Filosola) and 18.0±0.5 Ma (near Catati). Fauna collected in the flood plain sediments of Nazareno basin was assigned to the Friasian (Oiso, 1991) and a armadillo armor discovered near Suipacha (Castellanos, 1925) was attributed to the Late Miocene (Hoffstetter, 1977). In the southern part of the Tupiza basin, an $^{40}Ar/^{39}Ar$ age of 12.79±0.12 Ma has been obtained (Gubbels et al., 1993). A volcanic ash layer interbedded with sediments covering the San Juan de Oro Surface yielded $^{40}Ar/^{39}Ar$ ages of 9.32±0.12 and 8.78±0.17 Ma (Gubbels at al., 1993).

THE DEFORMATION OF THE CENOZOIC SEDIMENTS

The oldest sediments (Catati and Tupiza Fm) are the most intensively deformed. They have been affected by two tectonic events:

a) an early event, characterized by synsedimentary normal faults with relatively small displacements (about 1 m). Metric strike-slips faults, decimetric drag folds and hectometric oblique folds (oriented around N25° to N30°) are present along the Tupiza basin. These tectonic features are compatible with sinestral strike-slip shear process.

b) a late event is characterized by the development of N-S oriented fold with subvertical limbs.These folds are cut by a convergent thrust system. The Tupiza and Catati Fm have been transported to the center of the basin by thrusts with a detachment level in the black Ordovician pelites. Minor thrusts were developed from the gypsum levels of the Catati Fm.

The Nazareno Fm is overthrusted by the Tupiza Fm and its Ordovician basement (Quiriza Fault, Uralica Fault). On both the western and eastern edges of the basin the Cenozoic sedimentary infill is directly overthrusted by the Ordovician; these thrusts are convergent and the dip of these thrusts is gentle (10° to 15° eastward in Quebrada Epicaya for example). The total displacement of this thrusts is unknown.

The Oploca Fm, like the Nazareno Fm, is folded and thrusted but the deformation is less marked than in the Nazareno Fm. Geological mapping shows that the Oploca Fm progressively seals tectonic structures developed in the Nazareno Fm.

After the opening and infilling of these basins the waning of the deformation permits the progressive levelling of the reliefs surrounding these basins (formation of the San Juan de Oro Surface).

CONCLUSIONS

Three groups of tectono-sedimentary events have been recognized in the studied basins:

- the first one corresponds to the deposition of the Catati and Tupiza Fm. These sediments, as well as the alkaline lavas (Rondal Fm) associated with the opening of a transtensional basin, have arised from distributed left lateral shear. This event began before 23 my ago and ended before ≈ 20 my.

- the second one corresponds to the deposition of the Nazareno and Oploca Fm. These sediments were deposited in the basins of Tupiza, Nazareno and Estarca and correspond to different contemporaneous sedimentary wedges associated with N-S trending thrusts. In the Tupiza basin itself, these thrusts cross-cut the structures formed during the opening of the basin, and control the development of younger basins such as the Estarca basin which has been, in turn, transported to the west (piggy-back basin) during the development of the San Vicente Fault. The Oploca Fm was deposited at the end of this tectonic event which began before 20 my and finished after 13 my.

- the third one corresponds to the San Juan de Oro Surface formation which started around 10-9 my and corresponds with a quiescent tectonic period.

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