Evolution of the southern Altiplano Plateau during the Cenozoic

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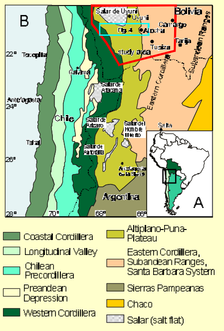


Fig. 1: Morphostructural units of the Central Andes and study area.

Introduction

The Altiplano Plateau forms a significant morphostructural unit (Fig. 1) bordered by the Eastern and the Western Cordilleras. The main focus of our project is to elaborate the temporal and kinematic framework of the Plateau development. In this context the initiation and evolution of the late Oligocene - Quaternary magmatic arc and its adjacent backarc are investigated. We carry out a combined analysis of basin and uplift history in its relation to the tectonic development. The data will contribute to the modelling of the evolution of the plateau.

From our present knowledge, four time periods were essential for the plateau development:
1. The **Late Eocene**, when the previous arc system ended with the Incaic tectonic phase around 40-35 Ma; a narrowing of the arc is assumed to have been caused by a break-off of the slab,
2. the **Oligocene** (35-28 Ma) corresponding to a gap in igneous activity, assumed as a result of a flat slab situation,
3. the **Late Oligocene to Middle Miocene** (28-12 Ma) with the installation of sedimentary basins and uplift of basement highs. Vertical movements were associated with an early phase of extensional and/or thrusting deformation in the eastern Altiplano, the Eastern Cordillera and the Western Cordillera, and the onset of intense magmatism,
4. the **Late Miocene** (ca. 11 Ma) phase of transpressional deformation which took place in the Altiplano and the Western Cordillera.

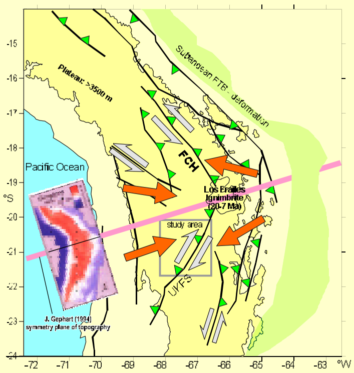


Fig. 2: Neogene kinematic pattern of the Altiplano (after Herail et al. 1997) and symmetry plane of topography according to Gephart (1994). It shows dextral transpression south of the symmetry plane and sinistral transpression north of it. The block between the SW-NE trending faults and the SE-NW trending faults has been pushed towards ENE, resulting in the intersection area in a maximum crustal thickness of about 79 km (Yuan et al. 2000) as well as extensive crustal melting in the Los Frailes area where peraluminous ignimbrites cover 10000 km². The symmetry plane of topography corresponds to the Euler equator of the Nazca/Farallon plate motion between 36 and 20 Ma (the same as the symmetry plane of the slab [not depicted]). According to Gephart (1994), the orientation of the symmetry plane gives evidence that the plateau originated in Late Oligocene-Early Miocene times.

Sedimentary record

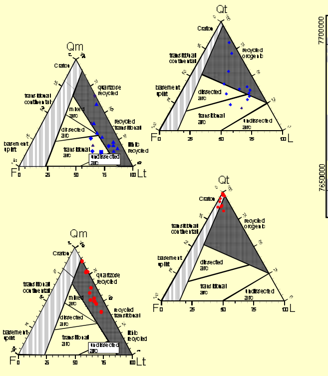
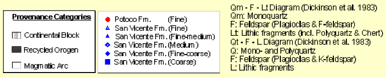


Fig. 3: Provenance analyses of Potoco and San Vicente sandstones. There is a change from a cratonic (to recycled orogen) source in the Potoco Formation to an arc-controlled environment in the San Vicente Formation.



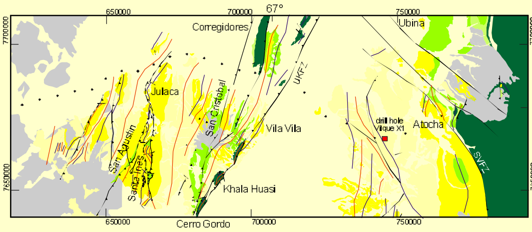


Fig. 4: Geological map of the southern Altiplano south of Uyuni (Fig. 1) with the outcrop areas and the main structural elements. UKFZ Uyuni-Khenayani Fault Zone, SVFZ San Vicente Fault Zone.

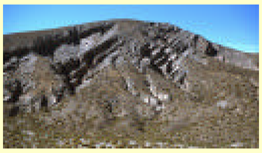


Fig. 5: Syntectonic sediments of the San Vicente Formation. Santa Ines Anticline.

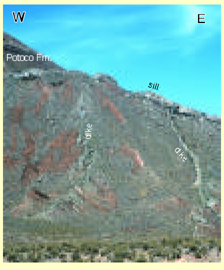


Fig. 6 Mafic alkaline dikes and sills in the Potoco Formation (probable age 27 Ma). The north-south trend of the dikes indicates East-West extension (cf. Fig. 10).

The Paleocene to Miocene basin fill of the Altiplano (Fig. 7) consists of continental deposits. The Paleogene Potoco Formation (Fig. 6) is widely attributed to a playa-mudflat environment. Considerable amounts of sands were fluvially transported into the basin from the Proto-Eastern Cordillera. The Oligocene-Miocene San-Vicente Formation represents variable facies conditions in active tectonic basins with intense magmatism (Figs. 5 & 10). Alluvial fans with abundant Paleozoic material were derived from uplifted blocks. Boulders of basement granites, gneisses and Permian volcanics are typical in the Santa Ines-Julaca area indicating a nearby basement high to the west. Volcanic edifices with lava flows were surrounded by pyroclastic rocks intermingling with epiclastites and fluvial to lacustrine sediments. Thicknesses of the San-Vicente Formation vary significantly over short distances. E.g., thickness is ~4 km west of the Corregidores Fault (i.e. in the hanging wall of this thrust), but only a few 100 m in small basins east of it (in the footwall). This contrast in thickness can hardly be explained by thrust-bounded basins, but rather by an extensional type of basin-formation. Extension is also inferred from alkaline dikes (Fig. 6).

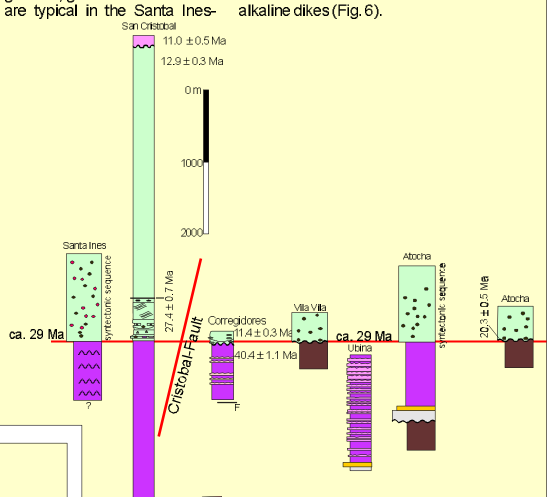


Fig. 7: Sections of the Paleocene to Miocene rock sequence of the Altiplano. Differences in thicknesses are pronounced between the San Cristobal area and Corregidores-Vila Vila which might coincide with a diachronous nature of the San Vicente Formation. These contrasts are interpreted to represent an extensional type of basin-formation. Angular unconformities are present east of the thrusts whereas in the depocenter contacts are conformable.

Structure and thermochronology

Fig. 8: Along the Corregidores Fault Silurian strata were thrust on pelites of the Potoco Fm. in Miocene times. Potoco strata show indications of dextral shear.

Fig. 9: Dextral shear in vertical sediments along the San-Cristobal Fault, a major branch of the Uyuni-Khenayani Fault Zone. Strata were brought into a vertical position during thrusting. Strike-slip displacement occurred subsequently to thrusting.

The Altiplano is cut by big faults (Figs. 4, 8 & 9) of the NNE-trending Uyuni-Khenayani Fault System (UKFS). The kinematic regime is transpressional comprising (predominantly) E-vergent thrusts and dextral strike-slip displacements. A first phase of thrusting deformation occurred presumably around 28 Ma, mainly in the San Cristobal-Corregidores areas (cf. Fig. 4). Ongoing thrusting is revealed by the syntectonic sediments of the younger San Vicente Formation (Fig. 5). Deformation lasted until 11 Ma. However, intervening periods of extension occurred around 27 Ma, revealed by north-south trending mafic dikes which are manifestations of a widespread alkaline magmatism during that time (Figs. 6 & 10), and the thickness contrasts in the San-Vicente Formation depicted in Fig. 7.

Magmatism

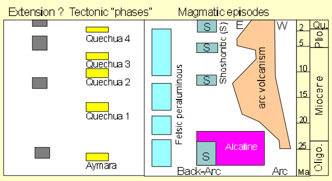
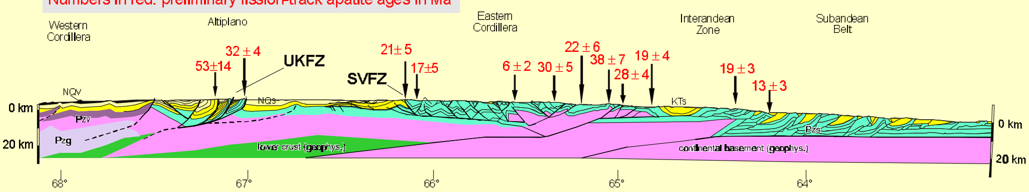


Fig. 10: Diagram showing the relationships between deformation and magmatic activity since the Oligocene (after Soler et al. 1993, ISAG).

The formation of the Altiplano plateau was accompanied by widespread magmatism. The igneous rocks reflect different tectonic regimes during the evolution of the plateau. In the late Oligocene magmatism was bimodal, felsic and mafic alkaline (Fig. 6, 10; Soler et al. 1993). In the latest Oligocene calcalkaline arc volcanism started in the Western Cordillera. In the Altiplano there was further felsic, peraluminous magmatism but also shoshonitic volcanism.

Section through the central Andean backarc at ~21°S

Numbers in red: preliminary fission-track apatite ages in Ma



Symbols: KTs: Cretaceous-Tertiary sediments; **Pzs**: Paleozoic sediments; **Pzg**: Paleozoic granitoids; **Pzv**: Paleozoic volcanics **NQs**: Neogene - Quaternary sediments; **NQv**: Neogene - Quaternary volcanics; **UKFZ** Uyuni-Khenayani Fault Zone; **SVFZ** San Vicente Fault Zone

Fig. 11: Preliminary results of apatite fission track analyses of rocks from a section through the Andean backarc (ca. 21°S, for morphostructural units compare Fig. 1). In the Altiplano and Eastern Cordillera a first cooling occurred in Late Eocene to Oligocene times. Miocene cooling occurred along the western and eastern margins of the Eastern Cordillera and in the Interandean zone. The older ages (around 30 Ma) presumably correspond to initial plateau uplift (the first contractional phase in the Altiplano and Eastern Cordillera). The younger ages may correspond to uplift along thrust faults and associated exhumation of the hanging walls. The considerable difference in age at the Interandean/Subandean boundary reflects the jump of deformation toward the foreland.

Conclusions

The Oligocene-Miocene history of the Altiplano shows a complex interplay of magmatism, sedimentation and tectonics. In contrary to many current models, the beginning of plateau formation was not only controlled by orogen-normal shortening or transpression but also by orogen-normal extension.

In the latest Cretaceous the area of the present plateau had an elevation near sea level. The western part of the Eastern Cordillera was uplifted already the Paleocene. The Altiplano formed a closed basin since that time where the pelitic Potoco Fm. represented a widespread uniform playa environment. In the Late Oligocene (ca. 30 Ma) basement uplifts along faults of the later UKFZ came into being, resulting in an individualization of the former depocenter into smaller basins where the San Vicente Formation was deposited. At the moment it is still under discussion whether these early faults were thrusts or normal faults. This uncertainty is mainly due to a poor knowledge of the age of the lowermost San-Vicente Formation. Clear indications of Late Oligocene crustal extension are alkaline igneous rocks and pronounced thickness variations over short distances. Lateron (Upper Miocene) transpressional deformation resumed represented by angular unconformities, syntectonic sedimentation, thrusting and strike-slip faulting.

It seems that plateau uplift was not uniform but occurred in distinct areas which were separated by fault-bounded subsiding basins. As normal faulting with East-West extension seems to have been important during the Late Oligocene and Early Miocene, it is assumed that initial uplift was not only controlled by shortening but also by lithospheric thinning.