Landscape Evolution in Northernmost Chile (18.5°-19.5°S): its Implication in the Tectonic, Sedimentary, and Magmatic History of the Central Andes

Dieter Uhlig (1), Hartmut Seyfried (1), Gerhard Wörner (2), Ingrid Kohler (1), Wolfgang Schröder (2)

1) Universität Stuttgart, Institut für Geologie, Herdweg 51, 70174 Stuttgart, Germany; email: dieter.uhlig@po.uni-stuttgar.de
2) Georg August-Universität Göttingen, Geochemisches Institut, Goldschmidtstr. 1, 37077 Göttingen

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Introduction

For about the past 20 Ma, the Western Andean Escarpment of the Altiplano in northernmost Chile (18°S) has had an extremely arid climate with intermittant periods of abundant (glacial?) water. In consequence, tectonic movements were only moderately compensated by erosion. However, the products of uplift, erosion and sedimentation are well documented. This results in an excellent geological record for the processes and timing of Andean uplift at the Western Escarpment near 18°S.
The landscape evolution of the Northern Central Andes between 17.5° and 19.5°S is characterized by :
(1) one of the driest deserts on earth with annual precipitation ranging from 2 to 330 mm depending on elevation (ABELE, 1984).
(2) one of the steepest gradients on earth from the subduction trench at > 7000 m.b.s.l. to > 5000 m a.s.l. of the Western Cordillera over a lateral distance of only 250 km. A Precordillera such as in the south does not exist. The Western Escarpment of the Andes rises to the Altiplano in a huge ramp, modified by one giant antithetically rotated block of 40km by 20km dimension.
(3) the lower parts of the Western Andean Escarpment and the Coastal Cordillera are dissected by several major valleys which all are up to 1200 m deep in the middle course (from N to S: Quebrada Lluta, Azapa, Vitor, Camarones, and Tiliviche). Such deep valleys are unusual for the Chilean Longitudinal Valley and Andean Front and result from enhanced precipitation and glaciers at high elevations (FISCHER 1991) in the geological past (and also today) depending on the influence of the subtropical high pressure zone.

Abstract

The landscape evolution of the Western Andean Escarpment at 18° S can be described as an interplay between individual stages of uplift, erosion, sedimentation, and gravitative collaps at various scales. Prior to the Miocene episode of Andean uplift, during the Jurassic and Cretaceous the region was characterized by low elevations, terrestrial redbed sedimentation and volcanism. Apart from the earlier Cretaceous and Jurassic units (arc and back arcs), the Longitundinal Valley represents the oldest and most persistent geological structure. It has accumulated sediments since at least 25Ma and is still active in its central undissected part. Structurally, it represents a half-graben formed between the eastward-tilted Jurassic Coastal Cordillera and the initial western Andean slope. Huge volumes of Miocene alluvial fan sediments, up to 1000m thick, derived from Cretaceous and minor Jurassic igneous rocks formed the ramp-like Western Slope of the Andes in northernmost Chile. These alluvial fan deposits distally grade into fluvio-lacustrine sediments east of the dam-like Costal Cordillera. This first sedimentary episode is interpreted as a first major stage of Andean uplift and crustal thickening: increased topographic relief in

combination with still abundant water produced the thick pile of alluvial sediments (c. 25 Ma to 20 Ma). This episode ended with the deposition of ignimbrite sheets of up to 900 m in total thickness. The age of the youngest ignimbrite sheet is 19.3 ± 0.01 Ma (Ar/Ar sanidine step heating age, Walfort et al., 1995) which is in perfect agreement with age determinations of Naranjo & Paskoff (1985) for the same ignimbrites. Crustal melting after a period of thermal relaxation (several Ma) and, probably continued magmatic input from the mantle wedge were responsible for the formation of the ignimbrites at around 19Ma. Alluvial ramps overlain by ignimbrites are also known from regions further south (20° to 21°S). Here, however, the ignimbrites are younger (16 to 17 Ma; Baker & Keynes, 1977) and the tectonic style affecting the ignimbrites in Late Miocene times is dextral strike slip (in the W Salar de Huasco pull apart basin) rather than normal block faulting (see below).
During the following short episode of volcanic and tectonic quiescence a westward oriented dendritic drainage pattern eroded the ignimbrites. Mafic andesite volcanism (Ar/Ar amphibole total fusion age: 18,7 ± 0.8 Ma) shortly followed the erosional event. The typical dense and mostly aphyric andesites of the shield volcanoes are found as characteristic detritus of the conglomerates of the Formaci6n Diabolo. This deposit, however, was considered by Tobar et al. (1968) and Vogel & Vila (1980) to be Quaternary in age. In our interpretation the Formaci6n Diabolo must be at least of Late Miocene age.

A second episode of uplift resulted in westward steepening of the Miocene sediment and ignimbrite ramp, normal faulting and antithetic rotation of the Pampa de Oxaya block. As a result, the Pampa de Oxaya today is tilted to an east dipping position forming a new, upper, half-graben within the upper reaches of the Western Slope. Lacustrine, fluvial, and alluvial fan sediments filled up this new sedimentary basin. Furthermore, tilting partly reversed the drainage pattern of the Pampa de Oxaya leading to sedimentation within the upper courses of its valleys. The extensional style of this movement is clearly documented by graben structures which cut the valleys of the Pampa de Oxaya. The age of the second stage of uplift must be younger than the initial andesitic volcanism (c. 18 Ma) and older than the 8- 9Ma old mammal fossils found within the upper half-graben sediments (SALINAS et al. 1991). Our conclusions contradict those of Muñoz & Sepulveda (1992) and Munoz & Charrier (pers. comm.) who interpreted their observations in the region as compressional structures. Compressional structures in our working area are limited to the Bel6n metamorphic basement rocks and their Createaceous cover. Although we cannot entirely exclude compressional tectonic structures of Late Miocene age, the *general* tectonic, topographic and morphological regime indicates extension, uplift and normal faulting rather than compression.
The Early Miocene ignimbrites and the overlying low angle mafic andesite shield volcanoes are restricted to the region between 17°S and 19°S, coinciding with the distinct structural and evolutionary style of the Western Andean escarpment described here.
An important secondary effect of the uplift of the Pampa de Oxaya was the partial oversteepening of its western slope which resulted in a giant gravitational collapse. The "Lluta Collapse" is exposed on both sides of the Quebrada Lluta for 20 km to the E of Poconchile. It covers an area of about 600 km^2 and displaced a rock section over 800m thick. This displaced mass is characterized by large tilted blocks and an unregular topography which in some places rises up to 200 m over the undisturbed ignimbrite ramp. Compressional faults are abundant in its lower parts. The collapse forms an amphitheater shaped scar E of the Pampa Plazuela. In the basal detachment zone of the collapse structure soft sediment deformations imply landsliding above a (wet?) clayey sand layer. Further, diatomite deposits were formed in small basins within the Lluta-Collapse area. The formation of these pure diatomite lakes, lacking significant clastic input by rivers, must be explained by groundwater seeping into small basins within the collapse. The ponds formed in this way provided constant suitable conditions for the diatomites independent of the typical fluctuations of rivers in dry climates. The giant Lluta-collapse thus shows several features suggesting the presence and potential role of an extensive ancient groundwater body in the collapse process.
The age of the collapse is difficult to establish : It must be younger than the second stage of tectonic uplift (8 - 19 Ma) but older than the development of the Lluta valley (> 3 Ma). This time span also falls into the time of formation of the upper half graben sediments and the lacustrine sediments of the lauca Basin (Kött et al. 1995), again indicating the presence of water more abundantly than during the Holocene. This landscape was sealed by the 2.72 ± 0.01 Ma (Ar/Ar sanidine age, Walfort et al. 1995) Lauca-Perez Ignimbrite which forms an extensive outflow sheet in western Bolivia and the Western Andean Escarpment (Schröder & Wörner, this meeting).

The incision of the deep valleys Lluta, Azapa, Vitor, Camarones, and Tiliviche finally dissected the Coastal Cordillera, the Western Slope and the tilted Oxaya block. By passing the Coastal Cordillera these rivers now gave way to all sediments to be carried directly into the sea. The 2.7 Ma Lauca-Perez ignimbrite entering the valleys of Lluta, Cardones, and Azapa - at least partly - postdates this dissection. Remnants of Lauca-Perez ignimbrite within a fluvial terrace 10 m above the valley floor and 500 m below the valley shoulders in the lower parts of the Lluta valley are evidence that erosion significantly had dissected the Western Slope prior to the ignimbrite event. These deeply incised valleys control the further history of the landscape in the Arica area. They truncate the Miocene dendritic drainage pattern leaving hanging valleys up to nearly one thousand meters above the valley bottoms. The walls of the major valleys are mostly undissected and smooth, showing steep slopes often with angles > 45°. Landsat imagery presents beautiful evidence for frequent collapse of these steep valley walls along most of its middle and lower course where incision reached up to 1200 m. The valley walls are subdivided by younger collapses formed by rotational sliding of blocks up to 400m in thickness and its conspicuous smooth detachment planes. Such landsliding often dammed the rivers evidenced by up to several tens of meters of lacustrine sediments upstream. Oversteepening of the valley walls during incision has certainly been the dominant cause for landsliding with earthquakes possibly serving as the ultimate trigger. The role of water as a lubricating (or instrumental) agent in the collapse process is difficult to evaluate. The water of allochthone rivers could not reach the detachment zone of the landslides which initiated above the valley bottom. Episodic heavy rainfalls could have provided abundant water even within a desert. However, such running water neither caused erosion to connect the hanging valleys to the main valley floors nor erased the character of the ancient dendritic drainage pattern still preserved since the Early Miocene. Obviously, the quantity of rain water was not significant and therefore could hardly cause the failure along the detachment planes. The only other possibility to provide water may be by groundwater. Prior to the incision of the deep valleys, aquifers within the permeable conglomerates of the Lower Oxaya Formation may have been charged by glaciers on the Altiplano. Incision of the valleys and the subsequent draining of groundwater aquifers may have produced the conditions for gravitational sliding along the oversteepened valley walls. Complete drainage of the groundwater and reduced recharge since about 3 Ma finally stabilized the valley walls.

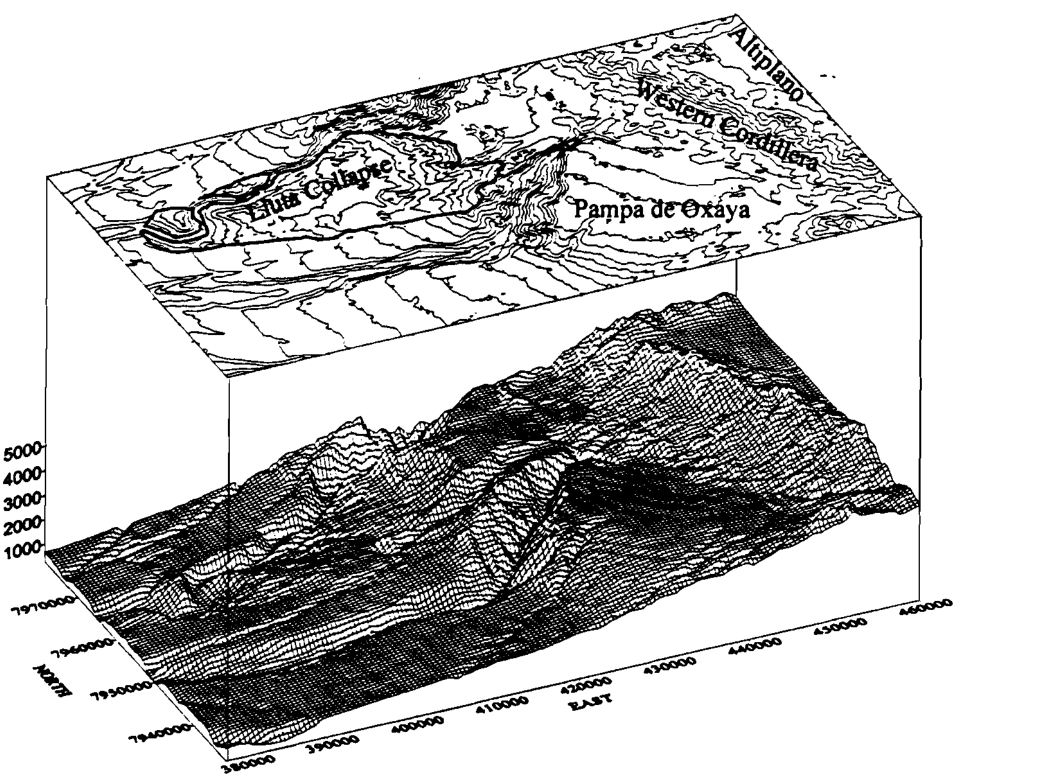

Fig.: Digital Elevation Model (UTM-Coordinates) of the tilted Pampa de Oxaya Block and the Lluta Collapse along the Western Slope of the Andes E of Arica

Conclusions

1)The landscape of the Andes between 17.5° and 19.5°S is the product of two main phases of uplift in the Early Miocene (c. 25 to 20 Ma) and Middle Miocene (c. 9 to 19 Ma), which both resulted in distinct episodes of erosion and sediment deposition.
2) Differential uplift and the formation of half-grabens were responsible for the present morphotectonic units: Coastal Cordillera, Western Slope, and Altiplano.
3) Since the Miocene the general tectonic style of the area has been uplift, normal faulting, and extension probably related to the frontal subduction of the Nazca Plate. This is in contrast to the southern Central Andes where subduction is oblique and tectonics are linked to strike slip processes.
4) The Formación Diabolo must be at least of Late Miocene age. The dissection of the Western Slope and the deposition of the Pliocene Lauca-Perez ignimbrite within these valleys clearly postdate this sedimentary sequence.
5) Oversteepening of the Western Slope resulted in a giant gravitational collapse covering an area of about 600 km^2. This "Lluta Collapse" predates the incission of the Lluta valley and is partly covered by the 2.7 Ma Lauca-Perez ignimbrite.
6) We presume an ancient extensive aquifer within the sediments of the Oxaya Formation. The Lluta Collapse and the landslides along the walls of the deep valleys could have been facilitated by water seeping onto the detachment planes. Furthermore, the pure diatomite deposits in the Lluta Collapse area probably arised from ancient lakes fed by groundwater.
7) Dissection of the Coastal Cordillera and subsequent headward erosion of deep valleys ceased sedimentation on the Western Slope. The steep walls of these valleys frequently collapsed and repeatedly dammed its rivers during incision.

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