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The Central Andes in Peru: 'Old' valleys in a 'young' mountain range?

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INTRODUCTION

Ignimbrites provide excellent regional markers for the tectonic and sedimentary evolution and the history of valley formation on the western slope of the Central Andes (Figs. 1 & 2). Rhyolitic ignimbrite sheets of several hundreds of km^2 in area and several tens to hundreds of km^3 in volume are of Miocene, Pliocene, and early Pleistocene age in southern Peru (Thouret et al., 2001, 2003; Paquereau et al., 2003; Sébrier et al., 1988). Our twenty Ar^{40}-Ar^{39} ages apparently provide (1) four Miocene ignimbrite sheets: 22-24 Ma old 'Nazca-Puquio' and 'Carumas' ignimbrites, 18-19 Ma old 'Alpabamba' ignimbrites, and a large age range of 13 to 16 Ma, and 9 Ma for 'Huaylillas' ignimbrites; and (2) three Plio-Quaternary 'Sencca' ignimbrite sheets dated at ca. 4.9, ca. 2-3, and 1.6-1.4 Ma. Opposite to the general stratigraphic scheme for southern Peru, most of the Sencca ignimbrites are in fact younger than the 'Barroso' lavas of the late Miocene and early Pliocene composite cones. Here we use ignimbrites and pyroclastic deposits as markers for the history and evolution of the deepest valleys in Americas.

IGNIMBRITES AND VALLEY EVOLUTION IN THE CENTRAL ANDES

The age of the deepest canyons in South America

The deepest canyons in the Andes were cut by Rios Cotahuasi and Ocoña in S Peru (Figs. 1 & 2). Elevation difference between the highest peaks cut by valley erosion and the valley bottom in their intermediate course is 2 to 3 km. Incision has exposed Oligocene-Miocene volcanic rocks overlying Precambrian and Cretaceous rocks in the deep sections of the valleys. The present valleys as well as older morphologies at their flanks suggest repeated filling by ignimbrites, lava flows and debris-avalanche deposits. Dated ignimbrites suggest that these canyons, cutting the western Cordillera and Altiplano, are 'old' landforms. This contradicts the current model of early uplift of the western Cordillera and rapid uplift of the Altiplano since the Pliocene.

Ignimbrites filling the Rios Cotahuasi and Ocoña canyons indicate valley incision at 3.8 Ma and 2.7 Ma. These canyons have been initially incised into a plateau mantled by Huaylillas ignimbrites dated at 13 - 14 Ma (Figs. 1 & 2). The younger ignimbrites that fill the upper part of these canyons down to a plaeo-valley floor some 300 m above the present valley bottom were dated at 3.8 Ma and 2.7 Ma. This indicates that the valley was cut and re-filled by pyroclastic deposits 1300 m thick between the Middle Mioceene and the Middle Pliocene (Fig. 1). Such filling suggests continuous uplift of the western Cordillera from 13-14 to 2.7-3.8 Ma, possibly followed by fast incision thereafter. Renewed downcutting of the canyon occurred after this infilling of ignimbrites, as reflected by two terraces on the edges of the canyon.

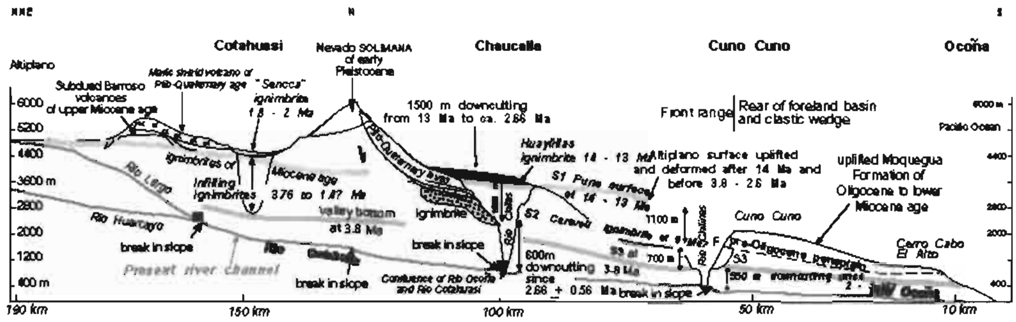


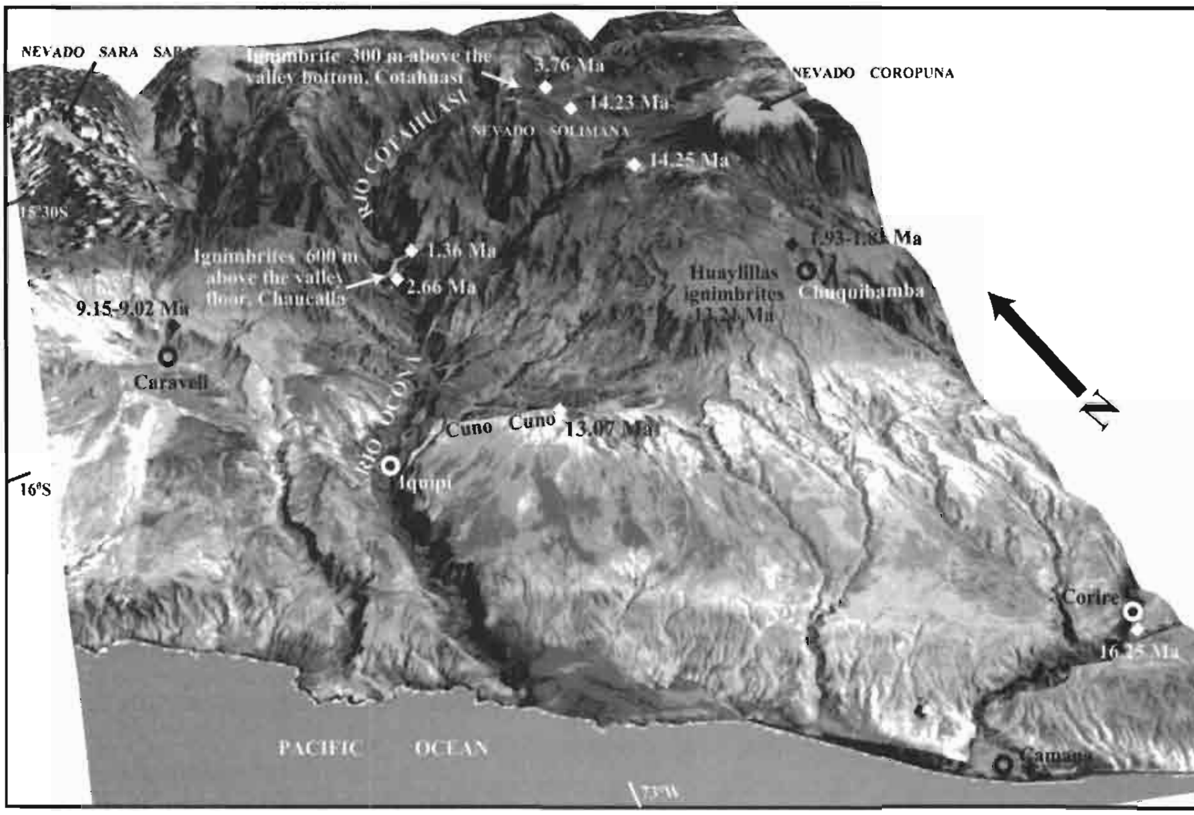
Figure showing the canyons of the Rio Ocona and Cotahuasi through the Western Cordillera, and four groups of ignimbrites (14 - 13 Ma, 9 Ma, ca. 3.76, and ca. 2.66 - 1.36 Ma). The amount of uplift and downcutting is estimated using the S1 (pink), S2 (orange), and S3 (green) palaeosurface and the ignimbrite tops. Green and blue indicate valley bottom and channel gradients at ca. 3.8 - 2.6 Ma and at Present, respectively.

Dating of the valley fills reveals the history of downcutting.

Ignimbrites crop out 1000-1300 m above the Rio Ocoña canyon on the SW flank of Nevado Solimana. These ignimbrites are inset in the valley at 2400 m asl, 1600 m below the plateau of the Huaylillas and Sencca ignimbrites of Rio Arma. They crop out 600 m above the present valley bottom and have been dated at 2.66 ± 0.56 Ma. Thus they do not correspond to the ca. 3.8-Ma-old valley bottom at 2700 masl in the Cotahuasi canyon. This indicates an increase in the present channel gradient compared to the one at 3.8 Ma (Fig. 1), which may be due to a new or faster incision between 3.8 and ca. 2.66 Ma. Alternatively, the break in slope upstream of the confluence may reflect differential uplift between the northern Cotahuasi canyon and the southern Ocoña canyon since 3.8 Ma.

The 3.8 – 1.4 Ma-old Sencca ignimbrites erupted well after uplift and valley cutting because they were channelled in valleys of late Miocene age. Upon reaching the western slope of the Andes, they expanded and mantled the S2 palaeosurface (covered by the Caraveli ignimbrites ca. 9 Ma), which is cut down in the S1 palaeosurface by 300 to 600 m. The Caraveli ignimbrites, deposited in shallow valleys cut in middle Tertiary sediments, eventually covered the Tertiary sediments of the piedmont and the older basement. The piedmont itself, Eogene in age, has been formed by the deposition of a clastic wedge of conglomerates and distal sand and siltstones as a result of uplift and erosion since about 25 Ma (Kennan, 1999). The 3.8 – 1.4 Ma-old Sencca ignimbrites then covered straths cut on the edges of the Ocoña canyon and tributaries at 300-400 m above the valley bottom.

A volume in excess of 90 km^3 has been removed in each canyon along the 140 km-long course of the valleys. At least ¾ of the volume was removed by 3.8 – 2.7 Ma. The average incision rate (190 m Myr^{-1} at. Cotahuasi) is inferred from the depth of the channel. The incision rate was relatively low (210 m. Myr^{-1}) between 13 and 9 Ma, but this rate probably accelerated twice between 9 and 3.8 - 2.7 Ma, as exemplified by a 1200 m-high break in slope over a valley reach of 30 km near the confluence. The incision rate was so fast after ca. 1.4 Ma that the Rio Cotahuasi cut down the valley fill at 1200 m Myr^{-1} above the town of Cotahuasi, meanwhile the Rio Ocoña and its tributary Rio Arma cut down as much as 1400 m in the volcanic fill since 1.4 Ma. Fast rates suggest increasing runoff and/or easy erosion of a poorly indurated pyroclastic valley fill.



WHAT CAUSED VALLEY INCISION SINCE 4 MA?

Two processes can initiate valley cutting and accelerate erosion: (1) changing base level of the rivers either by increased uplift or a fall in sea level, or (2) increased runoff due to climatic or meteoric changes.

Huaylillas ignimbrites 13 - 14 Ma old at the flanks of the western Andes in S Peru are only mildly folded and only within a few areas, indicating limited crustal shortening at least in the region between the High Plateau and Coastal Cordillera since that time. If the palaeosurface has been tilted by only 2 degrees, this would result in uplift from about 2500 m to 4000 m asl. in the area of Chuquibamba (Fig. 2). Thus, more than half of the entire observed uplift (=about 2000 m) of the Western Cordillera may post-date the emplacement of the Huaylillas ignimbrites and thus is younger than 13 Ma.

Given the evidence for an earlier phase of uplift from the thick conglomerate sections below the Huaylillas ignimbrites, this suggests a second or continued phase of uplift between 13 - 14 Ma and 3.8 Ma prior to valley cutting. We favour a fairly continuous phase of uplift mostly through tilting in that area of the Western Cordillera instead of the series of compressive phases suggested by other workers on independent lines of evidence (e.g. Sébrier et al., 1988). We argue that uplift was more or less continuous, and that downcutting may have taken place before 9 Ma but most likely before 3.8 Ma, and again before 2.7 Ma, based on dated valley infillings. Therefore, valley cutting was probably initiated by climatic changes, resulting in glaciation of the high Andean peaks and increased discharge onto the western Andean slope. Clapperton (1993) argued that glaciation started after 3.27 Ma in Bolivia, somewhat later than the first deep valley cutting as observed by us in southern Peru.

CONCLUSIONS

The deepest and largest canyons in the Andes are unique features that provide a source area and depocentres still connected by the same river system. From our studies we conclude that the deep valleys of S Peru had been cut down to near their present depths as early as 3.8 Ma. By contrast, at 13 – 14 Ma there existed a gently sloping 'Puna' peneplain, mantled by widespread Huaylillas ignimbrites. Initiation of valley cutting about 9 Ma may have been a response to continuous uplift after 13 Ma, that started earlier towards the western Altiplano than on the front range. By contrast, most of the downcutting, before 3.8 Ma and ca. 2.6 Ma, due to increased runoff, was probably controlled by climatic changes, perhaps due to the onset of Andean glaciation in the late Pliocene. There is no evidence for linking renewed downcutting at the end of Pliocene with an increase in uplift rate after 3.8 Ma or with isostasy due to glacial erosion after 2 Ma.

By contrast, valleys in southernmost Peru and in northern Chile are shallower and younger; they hardly cut the Altiplano (Wörner et al., 2000, 2002). Overall, valley incision is much less pronounced, younger and restricted to the western margin of the Altiplano plateau compared to S Peru (Fig. 1). Incision of drainage networks therefore took place earlier in the northern Central Andes, suggesting a faster uplift rate in the northern part toward the end of the Miocene. The increase in the size and reach of the valleys from S to N is a climatic signal as it parallels the present gradient with increased precipitation towards the N.

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