ARIDISATION AND ENHANCED RATES OF FLUVIAL INCISION IN THE ANDES OF NORTHERN CHILE

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RESUME

Les Andes situées dans la partie septentrionale du Chili ont subi une phase importante d'incision qui est caractérisée par une érosion rétrograde résultant de l'établissement d'un 'knickpoint' classique dans le profile longitudinal des cours d'eau. Cette phase d'incision plus prononcée a débuté il y approximativement 3 Ma, alors que le climat devint hyperaride dans le nord du Chili et que les précipitations allaient être restreintes aux Hautes Andes. Nous interprétons que ce changement climatique, représentant la transition entre un climat semi-aride à hyperaride a initié la phase majeure de formation des vallées.

INTRODUCTION

The Western Escarpment of the Andes of Northern Chile are a tectonically active mountain belt that is characterized by the presence of gently folded surfaces (or pediplains) tens to hundreds of km^2 wide and >1500 m deep valleys that dissect these surfaces (Fig. 1). Although that erosion in these valleys scales rates of relief formation, and despite the fact that these valleys form the most impressive geomorphic features in this part of the Andes, determinations of ages of incision, and more important, interpretations of possible controls on valley formation have been controversial. Depending on interpretations of relationships between ages of surfaces into which incision has occurred and geometries of the drainage network, phases of enhanced rates of incision have been considered to be the result of (i) an eustatic sea level fall, (ii) onset of glaciation in the Pleistocene (which is considered to have increased fluvial runoff) and (iii) differential tectonic movements (see Garcia et al., 1999, and Wörner et al., 2002 for overview of hypotheses).

Here, we present geomorphic and stratigraphic data from the Arica area, Northern Chile, based on which we show that a phase of enhanced fluvial incision rates was initiated in the Late Pliocene at ca. 3 Ma, at a time when climate became hyperarid in the Atacama Desert, and when precipitation became restricted to the High Andes (Hartley & Chong, 2002). We will interpret that this change in palaeoclimate resulted in stabilization of the surfaces in the lower reaches (formation of a salt crust on the Oxaya and Diablo Surfaces), which caused the sediment discharge from the surfaces to the fluvial transport systems to decrease. This change in the pattern of sediment yield is likely to shift the transport systems to the stage of undercapacity, which, in turn, promotes downcutting and backward erosion.

GEOMORPHIC ELEMENTS

The landscape of the study area consists of two major landform elements that blanket the Western Andean Escarpment in a N-S direction. The Oxaya Surface in the east (Fig. 1) forms the top of the Oxaya and Azapa Formations. These units are made up a > 1000 m-thick succession of tens of m-thick ignimbrite sheets and interbedded fluvial clastics (Carcia et al., 1999; Wörner et al., 2002). Dating of ignimbrites yielded ages of between 25 and 19 Ma for the Azapa and Oxaya Formations (Carcia et al., 1999; Wörner et al., 2002 and references therein). Deformation of the Oxaya Surface caused formation of the Oxaya anticline that displays an amplitude of >500 m, and thrusting along the Ausipar fault (Fig. 1). West of this fault is the Diablo Surface. This geomorphic element is made up of a several tens to hundreds of m-thick succession of fluvio-lacustrine sediments (Carcia et al., 1999; Wörner et al., 2002) that onlap eastward onto the Oxaya Surface west of the Ausipar fault (Fig. 1). The age of the top of the Diablo Formation becomes successively younger towards the south. Indeed, in the Arica area, accumulation of sediment is considered to have terminated in the Upper Miocene (e.g. Wörner et al., 2002). Approximately 100 km farther south (Tana valley), the top of the Diablo Formation is made up of a >70 m-thick succession of calcrete beds, marginal lacustrine limestones and stromatolites. This facies association, dated to have established between ca. 6-3 Ma, appears to be widespread in the Western Escarpment of Northern Chile and is considered as an isochronous marker horizon (Hartley & Chong, 2002, and references therein).

INCISION INTO THE OXAYA AND DIABLO SURFACES

The topographic data of the Arica area reveals that growth of the Oxaya anticline that occurred sometime between the Middle and Late Miocene (Wörner et al., 2002) caused the rivers to cut down to the base level of the Camarones valley (Figs. 1, 2). After the Late Miocene, the rivers feeding the Micoene Camarones river were rerouted in a southward direction into the Azapa drainage system (Figs. 1, 2), and the Camarones valley became abandoned. Because the sediments of the Diablo Formation onlap onto the Oxaya Surface in an eastward direction, and since the elevation of the easterly tip of the Diablo Surface corresponds to the elevation of the Camarones base level, it is likely that the Camarones river represented one of the feeding systems of the fluvio-lacustrine deposits of the Diablo Formation.

The phase of aggradation (which resulted in accumulation of the Diablo Formation) was succeeded by a phase of rapid incision and backward erosion resulting in a significant increase in relief (Figs. 1, 2). At present, the location of enhanced vertical and backward erosion is found immediately west of the knickpoint of the stream profiles (Fig. 2) There the bedrock is exposed on the channel floor, and the hillslopes are oversteepened. In the lower valley reaches, however, accumulation of sediment and long-wavelength meandering has resulted in establishment of wide valleys with planar bases, which increase in width downstream. In the upper reaches above the location of active incision and backward erosion, the geomorphologies display relatively smooth hillslopes with parabolic cross-sectional geometries indicative of a more mature landscape.

The geomorphic characteristics of this stage of enhanced rates of vertical and backward incision are found all along the Western Escarpment of the Andes of Northern Chile for which we assign an age of Late Pliocene for initiation. Indeed, the youngest sediments that are cut by fluvial incision represent the fluvio-lacustrine sediments found in the Tana valley ca. 100 km south of Arica. As discussed above, these sediments were presumably deposited between ca. 6-3 Ma as a result of a humid phase (Harley & Chong, 2002).

CLIMATE CHANGE AND VALLEY FORMATION

As outlined above, the stratigraphic data from the Western Escarpment of Northern Chile imply an age of ca. 3 Ma for initiation of the phase of enhanced incision. This time, however, is characterized by a shift from more humid climatic conditions to a hyperaric climate especially in the Atacama Desert (Hartley & Chong, 2002). As a result, precipitation became restricted to the High Andes where the major rivers are sourced that deeply cut into the Oxaya and Diablo Surfaces. The hyperarid conditions that established in the lower elevations of the Northern Andes of Chile caused the Pliocene strata to become covered by a thick crust of salt and anhydrite that even blanket hillslopes and summits. We interpret that this stabilization of surfaces decreased the sediment discharge from e.g. the Oxaya and Diablo Surfaces (Fig. 1) to the fluvial transport systems, shifting the rivers into the stage of undercapacity. In case that the fluvial systems are transport-limited, then a decrease in sediment discharge especially at lower elevations causes incision and backward erosion to increase. In support of this hypothesis, a change towards enhanced arid conditions is anticipated to increase the ratio of high-magnitude floods, i.e. the frequencies of large floods, which, in turn, is likely to contribute to the enhancement of incision and backward erosion (see also Tucker & Slingerland, 1997).

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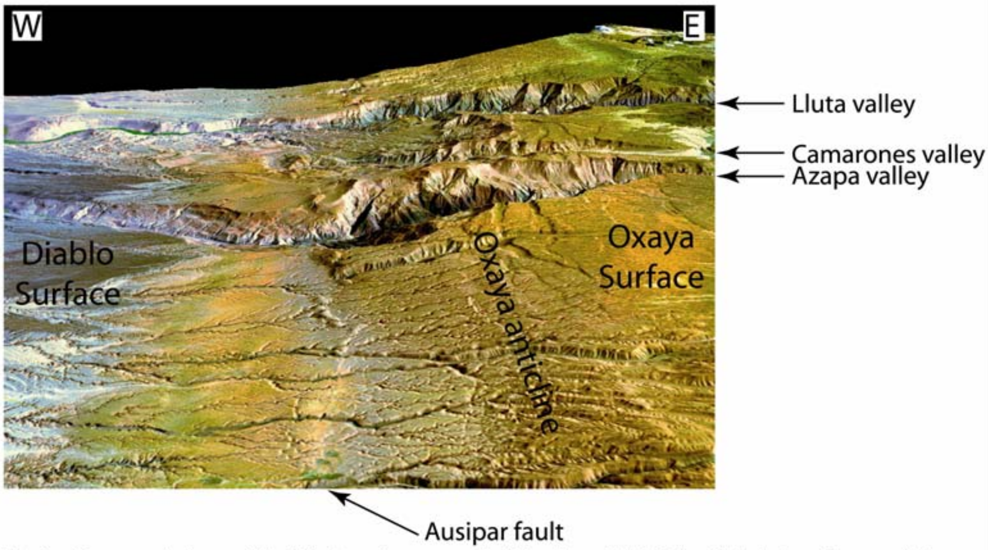

Fig. 1 Geomorphology of the Western Escarpment of Northern Chile. The digital elevation model has a spatial resulution of 50 m.

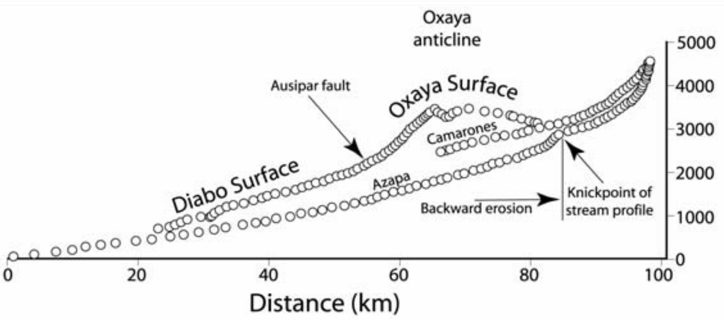

Fig. 2 Stream profiles, elevation of base levels and knickpoint migration of the Azapa river. See Fig. 1 for location