Debris flow deposits and El Niño events trough the Holocene on the hyper-arid coast of Atacama Desert, Northern Chile

Gabriel Vargas[1,2,3] & Luc Ortlieb[2]

(1) Département de Géologie et Océanographie, Université Bordeaux I. Avenue des Facultés, 33405 Talence Cédex, France.
(2) Institut de Recherche pour le Dévéloppement. 32 Avenue Henri Varagnat, F-93143 Bondy Cédex, France.
(3) Departamento de Geología, Universidad de Chile, Plaza Ercilla 803, Santiago, Chile

The present-day hyper-arid climate of the Atacama Desert is mainly controlled by the position and strength of the South-east Pacific subtropical anticyclone (SPA) and a series of ocean-atmosphere interactions. On the coast of northern Chile, debris-flow events are directly linked to exceptional and intense rainfall episodes (>20mm/3hr). Between central and northern Chile, rainfalls diminish from semiarid conditions at 27°S (La Serena, 115 mm/yr) to the hyper-arid desert at about 18.5°S (Arica, 1 mm/yr). South of 30°S, in central Chile, rainfall is principally controlled by the seasonal influence of the westerlies, with positives anomalies during El Niño events (Rutllant & Fuenzalida, 1991). To the north of La Serena, and for most of the Atacama Desert coastal region, rainfall events are exceptional and related to warm phases of ENSO too. Historical data from reports and chronicles of the 19th and 20th centuries show that intense rainfall events in the Atacama Desert, systematically occurred during El Niño events, but also that many El Niño events (including some of the strongest ones during the last two centuries) were not characterized by anomalous rainfalls (Ortlieb, 1995; Vargas et al., 2000). Therefore an ENSO warm phase regime appear as a necessary but not sufficient condition in the control of rainfalls able to produce debris-flows, in this area. The last major rainfall event in northern Chile (1991) was related with a weakened SPA and the presence of an anticyclonic cell over the extreme SW of South America (Bellinghausen Sea) which blocked the westerlies and induced a northward shift of the storms (Garreaud & Rutllant, 1996).

Rainfall occurrence and alluvial events in the Antofagasta area (23.4°S; 4.3 mm/year) also seem to be related with interdecadal variability of the ocean-atmosphere conditions in the Pacific Basin (Zhang et.al., 1997 ; Garreaud & Battisti, 1999). As shown in Fig. 1, « intense » rainfall episodes were more frequent between 1925 and 1941, and after 1982, and the two major events of the 20th century occurred in 1940 and 1991 (Vargas et al., 2000).

The study of alluvial deposit sequences in the Antofagasta area helps to interpret climatic changes during the Late Quaternary, and the impact of the El Niño phenomenon during the Holocene. The major geological and paleohydrological manifestations of climatic changes during the Late Quaternary, in the Antofagasta region, were previously examined (Vargas & Ortlieb, 1998). The similarity of several sedimentological properties (thickness, sorting, internal structure) of present-day debris-flow deposits and those which postdate the episode of high seastand during the Marine Isotope substage 5e (120-80 ka ?) suggests that, like nowadays, the last interglacial climate was characterized by a strong aridity and the occurrence of rare, intense rainfall events. During the last glacial period (late Pleistocene), reddish and thin layers piled up on some aggrading alluvial fans along the coast, while the rains were more frequent and of minor intensity. The last wet period occurred contemporaneously with the Last Glacial maximum, as inferred from stratigraphical record and new geochronological data. In the Holocene, the hyper-aridity resumed, causing a progradation of the alluvial fans and generating a new geomorphologic unit (Vargas & Ortlieb, 1998).

During the Late Pleistocene-Early Holocene transition, a drastic climate change is documented by geological and archaeological evidences. In the Antofagasta area, the end of the aggradation phase of the alluvial fans is marked by a short episode of eolian sand accumulation (in widespread layers and dune deposits) that covered the former alluvial deposits. This episode is interpreted as the manifestation of intensified SW and W winds. It could be dated ca. 10,000 yr BP (uncorrected) thanks to a human occupation of the archaeological site Las Conchas (Chimba-13) which was penecontemporaneous with the eolian sand accumulation (Llagostera, 1979).

The best exposed Holocene geological sequence is located immediately to the south of Antofagasta (Fig. 2). Two small fans at the foot of the northern Chile Coastal Scarp exhibit several transversal sections. Because of the reduced area of their watersheds, which enable a fast response to intense rainfall events, the small fans have recorded in a representative way the occurrence of former rainfall events over the area. A few human artifacts found within the debris-flow deposits provided a preliminary chronological framework for the sequence. A piece of marine shell (*Fissurella sp.*) included at the bottom of the Holocene sequence yielded a 5,600 cal. yr BP age (5,570+/-60 yr BP), and charcoals sampled near the middle of the sequence was dated 920 cal. yr BP. These data suggest 1) that alluvial deposition was severely reduced during the Early Holocene (no intense rainfall episodes)

and 2) that El Niño manifestations (which compare with the present ones, in the same area) possibly began ca. 6000 yr BP. The small size of these alluvial fans and several good exposures of the sequences enabled us to identify and count the individual debris-flow deposits. In one of the alluvial sequence, the total number of Holocene units amounts to 42, with 21 units postdating 920 cal. yr BP and two layers deposited during the 20th century. Thus it is inferred a mean frequency of 2.3 alluvial events/century during the last millennium, estimate which is also supported by the evidence for 2 major events during the past century (Vargas et al., 2000, Fig. 1 and 2). The numbering of debris-flow deposits in two other transversal sections of the same fan yields totals of 46 and 36 units during the Holocene. Differences between sections are related to the geomorphologic position of each section within the fans. Some deposits situated at the bottom and in the middle part of the sequences are especially thick, suggesting that stronger (either more intense or more violent) rainfall episodes occurred during the middle Holocene. One of these particularly strong event occurred ca. 920 cal. yr BP.

The whole available data for the Antofagasta region is compatible with La Niña-like conditions during and immediately after the Pleistocene-Holocene transition. A general lack of rain during the early Holocene on the coast of northern Chile ended ca. 6000 yr BP. It was only in the Middle Holocene that the first manifestations of the warm phase of ENSO were registered in this area.

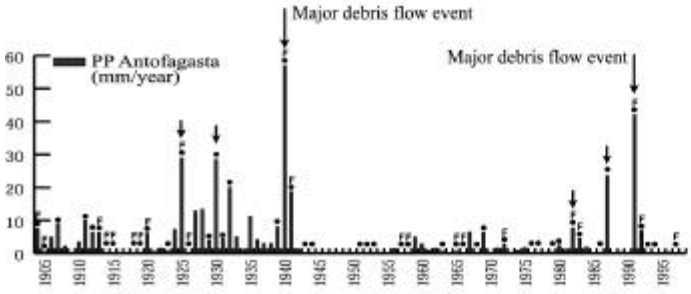

Fig. 1. Annual rainfall and debris flow or innondations events during 20th Century at Antofagasta. El Niño events are indicated by point, and the strong events by "F" (from Vargas et al., 2000).

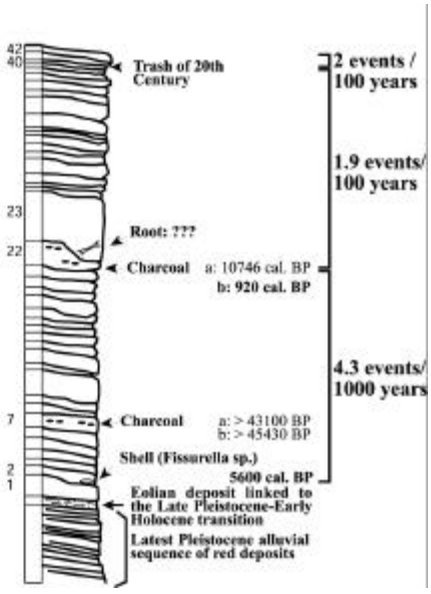

Fig. 2. Number of deposits in the Holocene unit at El Huascar area.

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