Catena 103 (2013) 62–73

Contents lists available at SciVerse ScienceDirect

Catena

journal homepage: www.elsevier.com/locate/catena

Fragile landscapes, fragile civilizations — How climate determined societies in the pre-Columbian south Peruvian Andes

B. Mächtle *, B. Eitel

Geographical Institute, Universität Heidelberg, Im Neuenheimer Feld 348, D-69120 Heidelberg, Germany

ARTICLE INFO

Article history:
Received 31 January 2011
Received in revised form 2 November 2011
Accepted 23 January 2012

Keywords:
Loess
Paleosoil
Holocene
ENSO
Archeology
ITCZ

ABSTRACT

This paper presents alternating periods of geo-ecological fragility and stability in a highly sensitive environmental setting: the desert-margin area of southern Peru (14.5° S). There, we have to state that fragility was dominantly triggered by climatic changes, which induced several oscillations of the desert margin. During the mid-Holocene, the study area received the Holocene maximum of precipitation, soil formation occurred and the desert retreated, as loess–paleosoil formation documents. In contrast, the Titicaca region further south-east experienced extreme drought at that time. This regional antagonism between humid and dry conditions was a result of meridional shifts in moisture transport across the Andes and occurred also during pre-Columbian times. Considering a coincidence between environmental and cultural changes, we state that success and decline of civilizations were dominated by hydrological oscillations, triggering fertility as well as a critical loss of natural resources. Fragile periods, i.e. periods of geomorphological activity, occurred contemporaneous with cultural transitions. In response to spatial changing resources cultural foci were shifted. So, the success of pre-Columbian civilizations was closely coupled to areas of geo-ecological favorability, which were directly controlled by distinct regional impacts of large-scale circulation mechanisms, including El Niño–Southern Oscillation (ENSO). This *spatial* view on non-uniform environmental and cultural changes has not been thoroughly considered before. Therefore, for the first time this paper offers geomorphological evidence for diachronous Andean (agri-)cultural development, which was *geographically determined*.

1. Introduction

According to Rohdenburg (1970), a system tends to a steady-state, which is equivalent to geomorphological stability. Periods of stability are reflected by distinct geomorphological processes and resulting landforms and sediments. Soil formation, loess deposition or fine-grained fluvial sedimentation characterizes periods of stability, whereas periods of the reorganization of the system are characterized by erosion, incision and formation of coarser sediment deposits. Reaching a new steady-state, a successive period of stability begins. Periods of transition can be triggered both by climatic oscillations and by man. Under steady environmental conditions, fragile landscapes do not occur. Landscapes' fragility rather may arise from long-lasting conversion of stabile landscapes by man, which is true for the majority of recently observed "fragile landscapes" (e.g. the Mediterranean or the Andean highlands). It is *a creeping disaster*, which may end in an existential loss of natural resources. The resilience of the ecosystem, which is defined as the buffer capacity of the natural system against changes in determining natural factors, is weakened by human over-exploitation. This advancement from hunters and gatherers via highly productive agronomic societies through to overuse and overpopulation, Messerli et al. (2000) defined as "trajectory of vulnerability".

1.1. Fragility as a relative term

However, fragility is a relative term. Depending on the resilience, the response of a specific system to such changes is individual. Well buffered, resilient systems (e.g. in mid-latitudes) show no nameable changes to a given order of climatic impact, while poor buffered, brittle systems as desert-margin areas – existing close to the edge – react very fast by passing internal thresholds. Desert margin areas are well suited for studies about environmental changes. They are defined as a reactive spatial system with low resilience, where the desert margin oscillates between a more humid and a more arid regional climatic state, which remains relatively stable over decades or centuries (Eitel, 2007). In this paper, we want to present the specific characteristics of such a system with low resilience: at the border of ecumenism, fragility may arise not from human impact, but from climatic changes. Human activity becomes apparent not in negative consequences, but in improved subsistence possibilities and reduced risks, modifying and stabilizing the environment e.g. by terracing. Here, stable systems experience fragility just during *temporal transition states* of reorganization of natural equilibrium.

* Corresponding author. Tel.: +49 6221 544577; fax: +49 6221 544997.
E-mail address: bertil.maechtle@geog.uni-heidelberg.de (B. Mächtle).

0341-8162/$ – see front matter
doi:10.1016/j.catena.2012.01.012

The high reoccurrence of fragility and stability in desert-margin areas leads to the formation of a variety of geoarchives. They offer clear evidence of environmental changes through time and therefore of recurrent transition periods of fragility.

1.2. The term “fragility” with respect to civilizations

Changing environments means changing resources — a fact that affects also the fragility of civilizations with an increasing degree of natural limitations. Considering the fundamental criticism of Hard (2011), who discards the man–environment paradigm or “Cultural Ecology” as inappropriate, “as society and culture as well as economics and politics had to be interpreted in principle … as responses to physical landscapes”, we want to substantiate its validity for the presence of man at the edge of habitability against it; therefore we defined under which conditions nature may act as a determinant for human activities. This should not exclude that even there some transition processes were triggered by man, but on the other hand there is striking evidence that dependence of man from nature and natural resources cannot be denied fundamentally. For a considerable time, interdisciplinary geo-archeological approaches strengthened the presumptive evidence about man–environment interactions and the supported conclusions, which Hard (2011) disregards.

Nowhere the natural thresholds are passed faster and with deeper impact than on desert margins due to their low resilience. Particularly there, civilizations experienced existential transitions in the old and new world. Environmental changes influenced directly cultural changes in many environments (cf. Hsu, 2000). In lower-latitude desert-margin areas, the loss of the main determinant water induces synchronous oscillations between ecumenism and desolation due to a high hydrological sensitivity. Under more humid conditions, these areas may be favorable for agriculture and societies are supplied by a secure subsistence potential. This is the ideal scenario for a cultural boom. During drought, these environments move rapidly out of the zone of ecumenism due to a critical decrease in the output of the land-use system. Civilizations react after an optional period of adaptation with migration, if the adaptation capacity (e.g. water harvesting measures) cannot compensate the loss of potential to support substantial human populations. This founds the clear concept of geo-determined human activities in desert-margin areas. This is the “reactive” behavior sensu Van der Leeuw and Redman (2002), hence cultural development is conditioned by environmental potentials and constraints. Amplified by the specific narrow topography, the south Peruvian coastal desert is an ideal region to study such resilience controlled, geo-determined human–environmental interaction. This study wants to examine the spatio-temporal link between environmental changes and cultural development and will hypothesize about the interrelationships of large-scale circulation.

1.3. Area of interest — the south Peruvian desert

The western cordillera of the southern Peruvian Andes (14.5° S) is characterized from east to west by semi-humid to semi-arid conditions, ranging from the Andean highlands down to the hyper-arid southern Peruvian coastal desert. Mean annual precipitation below 20 mm is responsible for extreme desert conditions there. On the western slope of the Andes, seasonal precipitation originates from Amazonian thunderstorms during Austral summer, which cross the western range of the Andes and reach the headwaters of some rivers, draining to the Pacific. On their western slope more and more decreasing rainfall is responsible for the formation of hydrological determined vegetation belts such as Puna, Pajonal and Matorral within short horizontal distances (Richter, 1981; Fig. 1). While the Puna is dominated by *Ichu* grasses, the Pajonal is a shrubland and the Matorral is dominated by several plant communities of cacti and xerophytes (Whaley et al., 2010). The extreme arid conditions of the coastal strip are caused by the steady influence of the SE Pacific anticyclone and the stabilizing effects of the cold Humboldt Current and its upwelling foci (Caviedes and Fik, 1992), which both prevent rainfall. Only along the river oases can vegetation thrive, the largely seasonal rivers crossing the desert to the coast are fed by highly variable rainfall in the more humid higher Andes. During the early/mid-Holocene, more humid conditions with mean annual precipitation about 200 mm were documented by the formation of a loess belt (Eitel et al., 2005).

1.4. Agronomic characteristics

According to the geo-ecological conditions, the study area can be divided into two agronomic zones:

1. The tropical warm *lowlands* of the wide desert oases in the Andean footzone (e.g. around Palpa and Nazca) are only limited by the availability of water. If water is abundant, the farming conditions are perfect and the yields are high, but the resilience of the system is poor due to the dependence on rainfall in the headwaters. Already a weak decrease in precipitation passes the threshold of resilience and the oases change to outer-ecumenism, dropping below the minimum potential to support a large human population.
2. The cold, always more humid Andean *highlands* are more resilient against hydrological fluctuations, but they offer limited yields due to temperature deficits. Most of the area, the Puna, is only good for pastoralism, whereas altitudinal limits of agricultural crops reduce cultivation on small-scale parcels along the higher elevated western slope of the Andes. Further to the Andean foreland, temperatures increase but precipitation decreases, so at present most of the western slope belongs to the outer-ecumenism.

This contrast in resilience is quantified from Rio Moquegua (17° S), where Satterlee et al. (2000) report a mean precipitation of 360 mm/yr in the headwaters, 260 mm of which is stored in the soils and 100 mm remains for discharge. A drop of precipitation over a period of years by 100 mm/yr results simplified in a total desiccation of the lowland river oases: the weak resilience of the oases becomes visible in 100% loss of discharge, while the headwater loss is merely the former abundance of the total precipitation and there the impact on the ecosystem remains weak.

2. New insights for a more comprehensive understanding of paleoenvironmental changes

Paleosoil formation offers new information about extreme spatial environmental contrasts in the south Peruvian Andes during the mid-Holocene. Despite its pending degree in detail, it represents already a key archive to understand superordinated climate mechanisms, which contributes to the comprehension of Holocene environmental changes in the study area.

2.1. The Palpa loess–paleosoil sequence

Located at 2200 m a.s.l. on a gently sloped, exposed plateau surface, the profile marks the eastern, most humid border of the loess belt, covering the western slope of the Andes. Further to the east, the increase in moisture induced nameable soil formation and weathering, slope processes and a mixing of dust and parent material and pure loess sediments diminish. In this study, we analyzed a loess–paleosoil sequence to specify the environmental conditions during the early to mid-Holocene humid period in the study area.

2.1.1. Samples and methods

Bulk samples were taken from each horizon, air-dried and the <2 mm fraction was analyzed. The carbonate content was determined using a Scheibler apparatus, the pH was measured in 0.01 M $CaCl_2$ (Schlichting et al., 1995). The content of soil organic carbon was