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Santander, 17-20 septiembre de 2012

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A. González Díez

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THE GEOMORPHIC DIMENSION OF GLOBAL CHANGE. RISKS AND OPPORTUNITIES. M. Hurtado, L.M. Forte, V.M. Bruschi, J. Bonachea, V. Rivas, J. Gómez Arozamena, M. Dantas Ferreira, J. Remondo, A. González, J.R. Díaz de Terán, L. Salas y A. Cendrero. **La dimensión geomorfológica del cambio global; riesgos y oportunidades.**

THE GEOMORPHIC DIMENSION OF GLOBAL CHANGE. RISKS AND OPPORTUNITIES

La dimensión geomorfológica del cambio global; riesgos y oportunidades

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Resumen: Se presenta la hipótesis de un cambio geomorfológico global, independiente del clima y con importantes implicaciones para los procesos y riesgos geológicos superficiales. Ese cambio, muy marcado desde 1950, se debería a la intensificación de las actividades humanas (dimensión geomorfológica de "the Great Acceleration"). Se aportan datos cuantitativos sobre indicadores de la importancia de actividades humanas que modifican el territorio y de procesos geomorfológicos, a diferentes escalas y coherentes con la hipótesis indicada. Los datos indican que, desde el punto de vista geológico, el inicio del Antropoceno podría ser el fin de la Segunda Guerra Mundial. De especial significado son los datos recopilados sobre los riesgos geológicos superficiales y su correlación con indicadores de actividad humana o de degradación del territorio. También se muestra que la aceleración de los procesos geomorfológicos abre oportunidades para explotar ciertos recursos geológicos como renovables.

Key words: global geomorphic change, Anthropocene, geomorphic hazards, human geomorphic footprint, mining of renewable construction materials
Palabras clave: cambio geomorfológico global, Antropoceno, riesgos geomorfológicos, huella geomorfológica humana, minería de materiales de construcción renovables

1. INTRODUCTION

Different types of data obtained by the authors in the last 20 years have led to the formulation of a series of concepts as well as a model to explain the present evolution of geomorphic processes. The aim of this contribution is to present those concepts and model, the data on which they were based, the tests carried out to validate it, and some of their implications.
An analysis of the temporal evolution of landslides in a small valley of Cantabria (N Spain) showed two periods (around 5500 BP and the end of the 18th century, coinciding with the Neolithic and industrial revolutions) during which landslide rates increased significantly. Climate changes did not seem to explain those increases but pollen and other evidences suggested that human activities could be a determining factor (González et al., 1996, 1999).
Later ork in a valley of Guipúzcoa (N Spain) revealed that landslide rate in the area had increased about one order of magnitude in half a century. Analyses of sedimentation rates in estuaries of the region revealed they had experienced similar increases during the same period. Again, rainfall change did not seem to explain such strong increases (Remondo et al., 2005, Cendrero et al., 2006). Increase in human activities also appeared to provide a more plausible explanation.
Parallel work on direct and indirect denudation due to human activities ("technological denudation"; Brown, 1956) in areas of Argentina and Spain (Rivas & Cendrero, 1996; Cendrero & Douglas, 1996; Rivas el al., 2006), showed that mobilisation of geologic materials by those activities could presently be, globally, one order of magnitude greater (or more) than the one due to natural processes. This massive modification of land surface seemed to have a strong reflection on

hazards due to mass movements (Remondo et al., 2005; Cendrero et al, 2007; Bonachea et al., 2008).

The results obtained led to propose the concept of "geomorphic dimension of global change" and later "global geomorphic change (GGC)" (Cendrero & Douglas, 1996; Cendrero et al., 2006; Cendrero et al., 2009). Also the concept of "human geomorphic footprint (HGF)", expressed as area of new anthropogeomorphic landforms, and volume of geologic materials mobilised by human activities, per year (Rivas et al., 2006). The latter authors suggested that there might be a "post-industrial model of geomorphic evolution", quantitatively and qualitatively different from the pre-industrial one.

The HGF and other land-surface modifications would be the expression of GGC, related to the intensity of human activities and leading to the increase of geomorphic processes' rates.

2. HYPOTHESIS AND VALIDATION

A hypothesis was formulated through a conceptual model that assumes the existence of the following chain of effects: *driving force* (increase in population, technological and economic capacity)–*pressure* (increase in human activities)–*impacts* on the *state* of the environment (changes in geomorphic processes and reduction of surface layer resilience)–*response* (increase in the rates of geomorphic processes, associated hazards and risks).

If the hypothesis were correct, there should be a general acceleration of the rates of geologic processes due to the interaction between water and land surface (hydrogeomorphic -HG- processes), and indicators of such acceleration should relate more closely to indicators of the intensity of human activities than to those of climate change.

To be able to test the proposed model, data were gathered, in study areas of very different human and geomorphic settings in northern Spain and the Rio de la Plata basin. Indicators of potential human and natural drivers as well as indicators of geomorphic processes' response were used. The natural driver considered was rainfall. As indicators of human drivers, population, GDP (total, not *per capita* Gross Domestic Product), energy and cement consumption were used. Livestock load, area devoted to agriculture, land-use change or road network were indicators of human pressure. Finally, sedimentation rate was the main geomorphic response indicator considered. Sediment cores were extracted and dated to determine sedimentation rates and previously existing determinations were also analysed.

The results obtained have been reported by Bonachea et al. (2010) and Bruschi et al. (2012). The great majority of study areas in both regions showed increases of sedimentation rates (by factors 3-12 in about half a century). The few cases with sedimentation rate stability coincided in general with areas in which human activity had not significantly changed during the period of analysis. These results are coherent with those reported by Syvitski et al. (2005) and Syvitski & Kettner (2011) for a large number of river basins in the world.

Rainfall in the different study areas during the same period showed stability in some cases, and slight increases or decreases in others. On the other hand, the magnitudes and trends of changes in indicators of human drivers were similar to those of sedimentation rates. That is, new data are on the whole coherent with the hypothesis, although not in every single case.

To further test the model the possible correlation between human drivers (mainly GDP) and disasters due to HG processes (floods, landslides) during the last century or so was explored. Correlation between the frequency of those disasters and GDP should be expected for several reasons. An increase in GDP reflects general socio-economic improvement and it should be reflected in both better data gathering and increased human exposure (more people, buildings, infrastructure, etc subject to hazards). Therefore, registered frequency of all types of disasters should be expected to increase with time. Another factor to take into account is climate change, which is reflected in greater frequency of extreme climate episodes (IPCC, 2007). This should affect both climate and HG disasters, but not geologic (volcanoes, earthquakes) ones. Finally, if the hypothesis presented here were correct, global geomorphic change would imply an intensification of geomorphic processes that should lead to greater frequency of HG disasters. In other words, if the model were valid, HG disasters should increase most, and then climate and geologic ones.

According to recent work by Forte (2011) this seems to be essentially correct. The analysis of this author was based on data on disaster frequency for most countries in the world, classified in three categories (geologic, climate, hydrogeomorphic) and grouped by regions and continents.

Among his findings: a) there is a general increase in disaster frequency, in all regions and continents;

Table 1. Correlation between GDP and disaster frequency, with no lag and 5 years lag for the latter.

CONTINENT	**No time lag GDP (1950-2008) Disasters (1950-2008)**	**5 year lag GDP (1955-2010) Disasters (1955-2010)**
	Hidrogeomorphic Disasters	
AFRICA	0.8689	0.8592
AMERICA	0.9177	0.9779
ASIA	0.9650	0.9471
EUROPE	0.7246	0.7455
	Climate Disasters	
AFRICA	0.8016	0.7704
AMERICA	0.9106	0.8633
ASIA	0.8595	0.8233
EUROPE	0.5679	0.5416
	Geologic Disasters	
AFRICA	0.5207	0.4571
AMERICA	0.6959	0.5373
ASIA	0.8234	0.7926
EUROPE	0.7461	0.6678

b) in the great majority of cases HG disasters increase most and geologic ones least; c) the increase is particularly marked after the middle of last century, coinciding with the increase observed in sedimentation rates (Fig. 1); d) correlation coefficients between HG disaster frequency and GDP vary between 0.72 and 0.97 for the different continents. Correlation is worse for other disasters, as expected (Table 1); e) correlation between the Land Degradation Index (FAOSTAT, 2011) and the increase factor of HG disasters in the last fifty years yields values between 0.76 and 0.83 in the different continents;

f) numerical data to correlate disasters and rainfall are not yet available, but comparison with results presented by IPCC (2007), suggest there is very limited relationship between both; g) there are some exceptions to this general rule at country level, few at region level and practically none at continent level; h) some correlations, such as GDP-disaster frequency in Asia or the Americas are strikingly good (Fig. 2), and strongly suggest cause-effect relationships.

3. IMPLICATIONS AND OPEN QUESTIONS

The results described point out to a significant change in the operation of geomorphic processes since around the middle of last century. The strong, roughly exponential increase observed in most cases in both sedimentation rates and HG disaster frequency, and their apparent relationship with human drivers suggest that indeed there is a people-driven “global geomorphic change”. Also, that there is a “Great Geomorphic Acceleration (GGA)” which coincides with the Great Acceleration (GA) of Steffen et al. (2011), triggered by the strong demographic and economic expansion after World War II.

If what the results thus far presented is confirmed, the observed increase in the risks due to surface geologic processes would be due mainly to geomorphic, not climate change. Mitigation efforts concerning those risks should therefore change their focus. Also, the marked change in surface geologic processes could be used as a criterion to define the starting point of the Anthropocene. That is, the beginning of this new period of Earth's history perhaps should not be placed at the moment humans acquired the potential to strongly transform Nature (end of the 18th century; Crutzen, 2002), but when those transformations actually occurred (end of World War II, and starting of the GA, including the GGA).

But, as is often the case, the new situation described not only represents problems, but also some opportunities. One of these is that accelerated denudation opens the possibility of mining renewable construction materials. Work carried out in the humid Pampa (Buenos Aires province, Argentina) has shown that silting (in some cases, total filling) of lakes has increased very much due to greater soil erosion caused by human activities. This implies the loss of such valuable areas, reduction of fishing potential and of flood-buffering capacity. At the same time, soil mining for brick-making is extensively practiced in the area, thus eliminating the A soil horizon and causing other forms of environmental degradation (Rivas et al., 2006).

Preliminary analyses indicate that: a) sediment accumulated in lakes (generatedmainly by erosion of the A horizon) has.

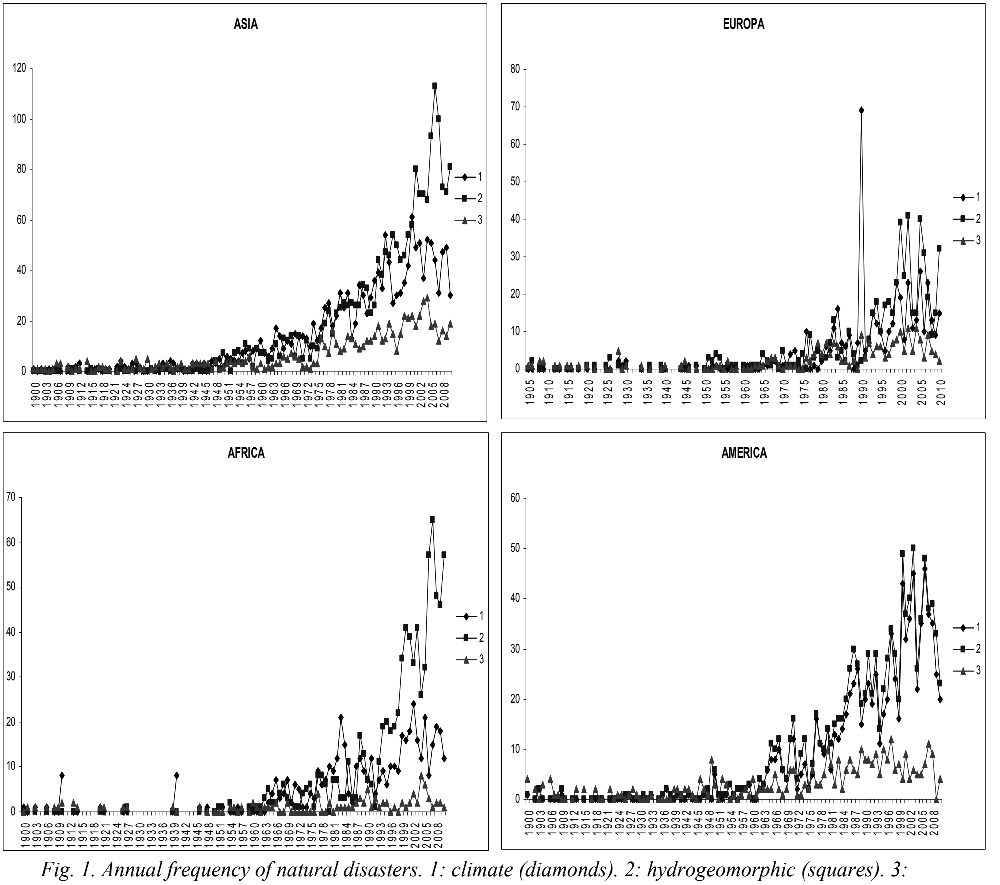

Fig. 1. Annual frequency of natural disasters. 1: climate (diamonds). 2: hydrogeomorphic (squares). 3: geologic(triangles).

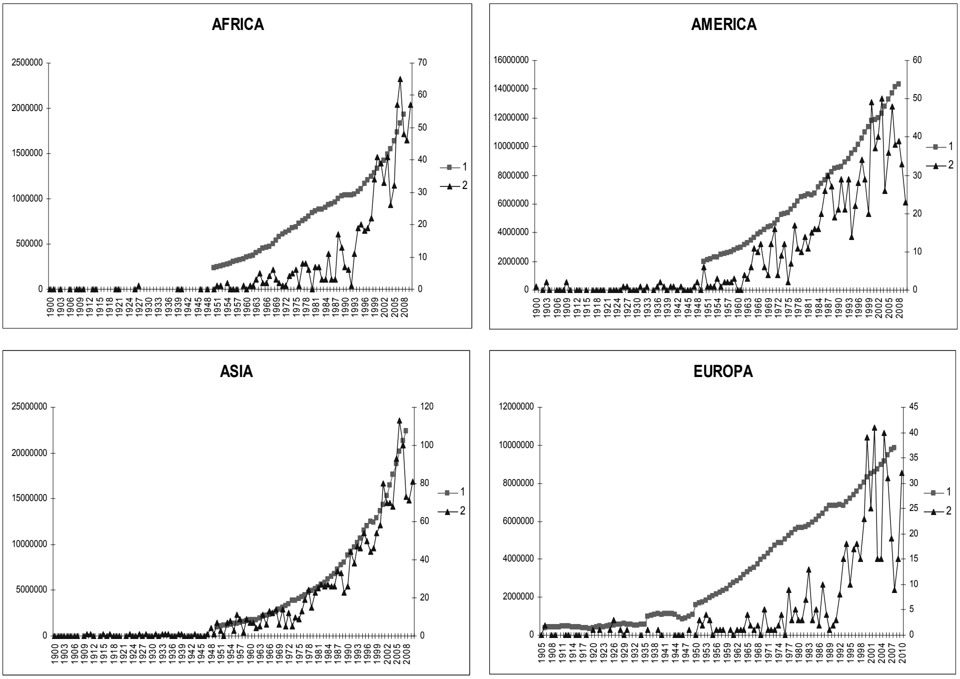

Fig. 2. GDP (1: squares, left scale, in $US) and Nº. hydrogeomorphic disasters (2: triangles, right scale).

physical and chemical properties similar or even better than the material usually exploited for making bricks; b) sedimentation rate seems to be high enough to "renew" the resource as it is exploited; c) extraction of sediment could allow to maintain or increase the depth of lakes or recover some recently filled; d) environmental impacts due to traditional exploitation methods could be significantly reduced. Work is presently under way to confirm the preliminary results indicated and assess the economic feasibility of exploiting this "renewable resource".

The implications of the model described are significant. It is therefore suggested that it should be further tested, if possible by other researchers and in other areas, to determine to what extent global geomorphic change is indeed a reality.

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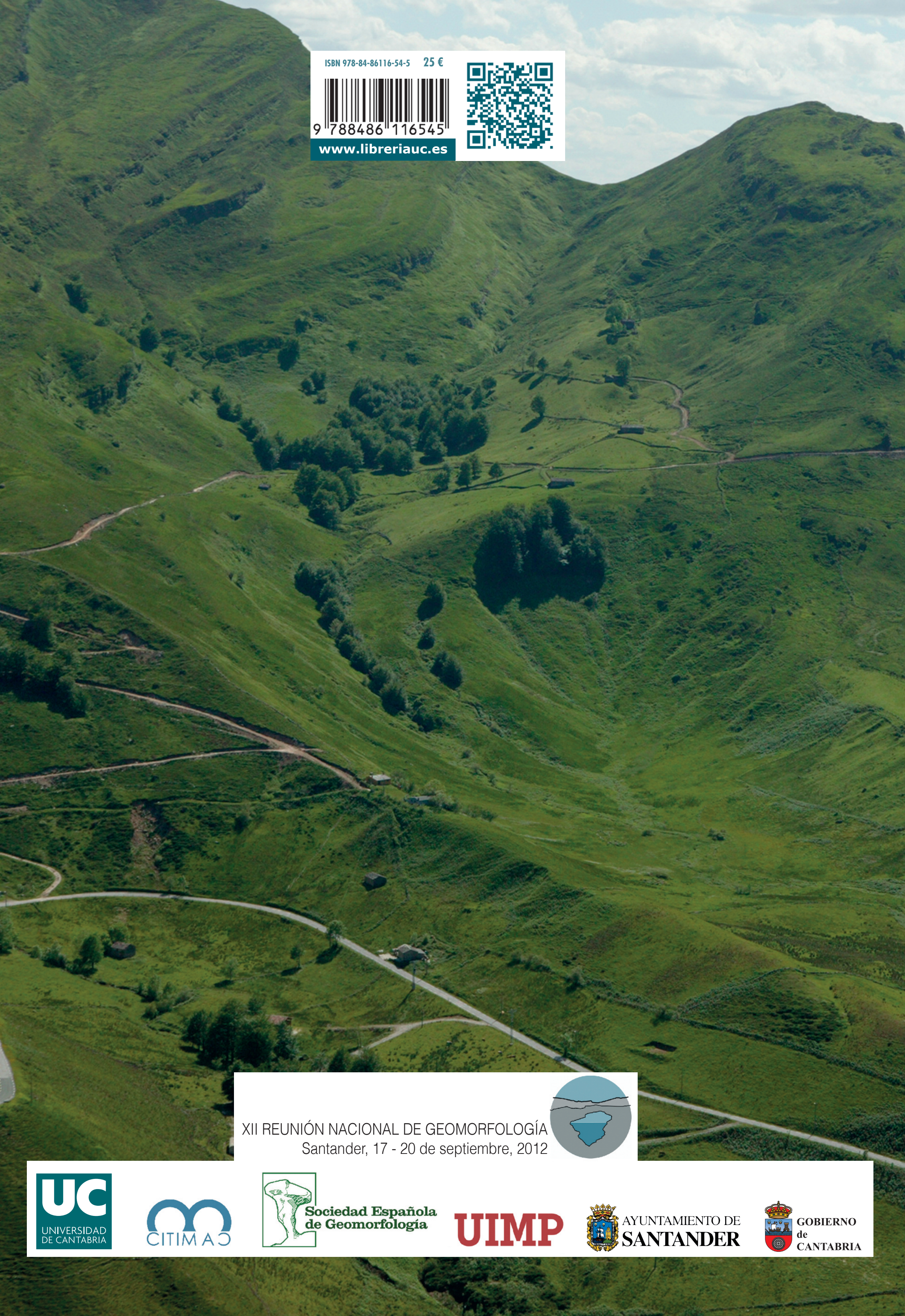

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