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Assessment of land subsidence associated with intense erosion zones in the Zacatecas and Guadalupe quadrangles, Mexico

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Abstract We performed a geological and geomorphological analysis in the Zacatecas and Guadalupe quadrangles. The objectives are the assessment of the role of the erosion in land subsidence and its association with the lithology and geological structures. The stratigraphic sequence of the study area is composed, from bottom to top, of the dominantly sedimentary Zacatecas Formation (ZF, Early Cretaceous). It is covered in transitional contact by the Las Pilas Volcanosedimentary Complex (LPC, Early Cretaceous). The LPC is composed of laccolithic intrusions and basaltic lava flows interlayered with fine grained sedimentary rocks. The LPC is in contact by unconformity with the Paleocene-Eocene Zacatecas Red Conglomerate (ZRC), which is a polimictic conglomerate composed of clasts of the ZF and LPC. Strata in the ZRC vary from well- to barely-consolidated. At the top there is an Eocene-Oligocene volcanic sequence composed of ignimbrites and tuffs that varies from welded to moderately welded. These rocks have been subject to compression during the Late Cretaceous and at least five extension stages during the Cenozoic. Geomorphological analysis was performed with the dissection density, general dissection density, maximum dissection depth and relief energy maps. Field mapping was focused on paleo-landslides and talus deposits. Based on the field mapping we defined that where dissection density >10 km/km^2, general dissection density >25 km/km^2, maximum dissection depth >130 m and relief energy >160 occur together they locate intense erosion zones. In these zones, the land subsidence is developed if the rocks are moderately to poorly consolidated, in loose talus deposits or in poorly compacted sediments. The erosion is greater if there are faults and/or fractures. The identification of the high erosion zones associated with land subsidence is a tool to identify hazardous zones that could be applicable in urban planning projects.

Key words erosion zones; geomorphology; Zacatecas and Guadalupe, Mexico

INTRODUCTION

The cities of Zacatecas and Guadalupe are the most populated and fast growing in the State of Zacatecas, Mexico (see inset in Fig. 1). In these cities, the urban development is only based in land use change that does not consider the environment and the geological/geomorphological processes that operate. Due to landscape modification and erosion, land instability is currently a common phenomenon, and is mostly developed over palaeolandslides and talus deposits.

Since a few years ago, several attempts have been made to identify and define the geological and geomorphological processes that currently operate in these cities (Enciso-De la Vega, 1994; Escalona-Alcázar *et al*., 2003; Escalona-Alcázar, 2009). On that basis, together with geological field mapping and by analysing topographic maps of the Zacatecas and Guadalupe quadrangles, in this work we introduce the first map with a model that defines areas with different erosion potential.

MODEL

The base maps were the topography scale 1:50 000 maps of the Zacatecas and Guadalupe quadrangles, with topographic contours at 10 m. The maps were divided into 1-km side squares. Based on topography, in each square the parameters measured were: (1) the dissection density

defined as the length (km) of creeks by km^2; (2) the general dissection density that is the length (km) of all topographic contours in a square kilometre; (3) the maximum dissection depth is the length (m) measured perpendicular from the highest elevation to the nearest bottom creek; and (4) relief energy maps, that is the difference between the highest and lowest points.

Based on field mapping of palaeolandslides and talus deposits we defined that they are located where the dissection density is >10 km/km^2, general dissection density >25 km/km^2, maximum dissection depth >130 m and relief energy >160. The areas defined by these parameters are called High Erosion Zones (Fig. 1). Medium ones are at: 8.5–10 km/km^2, 20–25 km/km^2, 100–130 m and 130–160, respectively (Fig. 1). Whereas the Low Erosion Zones are at: 7–8.5 km/km^2, 15–20 km/km^2, 70–100 m and 100–130, respectively (Fig. 1).

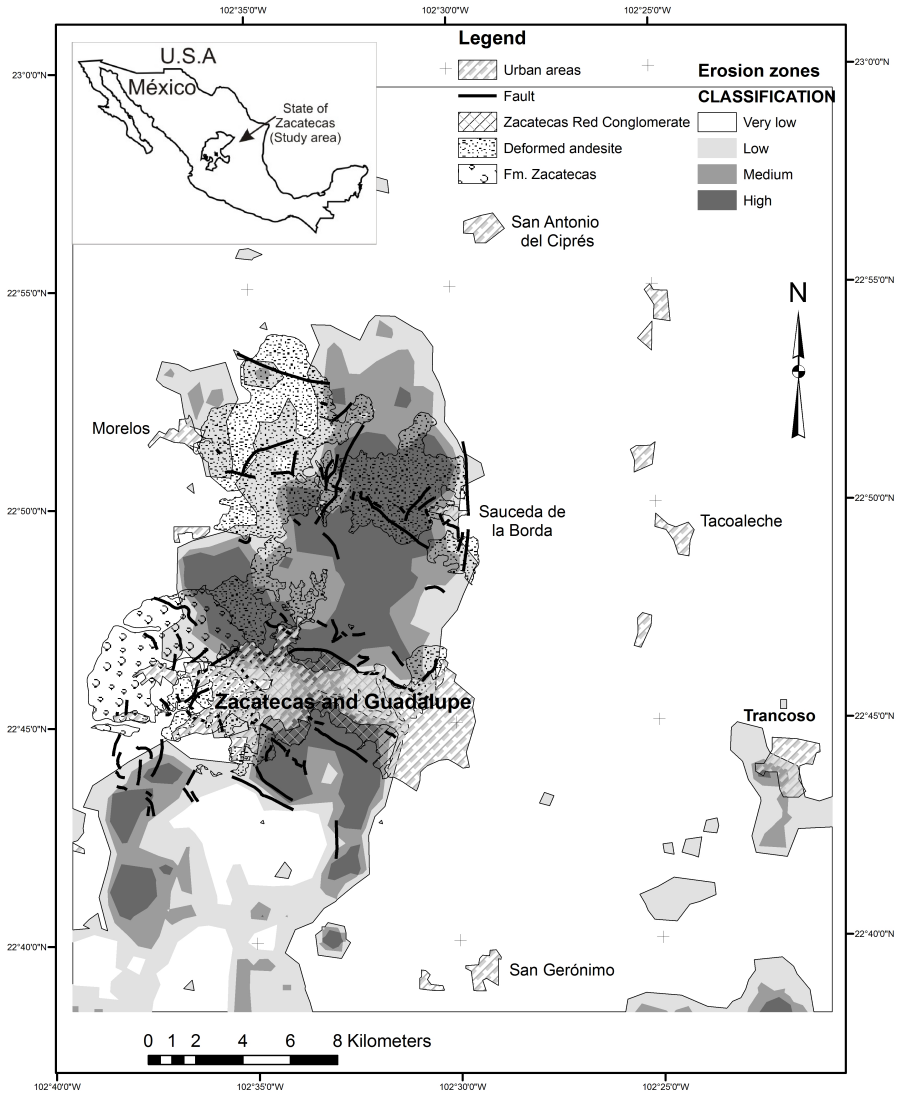

Fig. 1 Map showing the intense erosion zones (high, intermediate and low) of the Zacatecas and Guadalupe quadrangles. Inset: location of the study area.

The geological mapping was modified from Escalona-Alcázar and co-workers (2009). From the stratigraphic sequence, the lithologic units shown in Fig. 1 are the Deformed andesite, Zacatecas Red Conglomerate and Fm. Zacatecas because they have the more intense faulting and

fracturing; also the last two have easily erodible strata. High erosion zones are mostly associated with the Deformed andesite (Fig. 1). In these areas the sandy-rocky soils, less than 10 cm thick, are easily eroded.

The Intermediate and Low erosion zones are located in medium to low topography. In these areas the erosion removes material mainly from the Zacatecas Red Conglomerate and to a lesser extent from the Fm. Zacatecas.

The urban areas located over the Zacatecas Red Conglomerate are currently experiencing land subsidence and instability due to erosion. These processes are slow but continuous.

The zones proposed here are a tool to use in further urban development to avoid damage due to erosion effects to buildings, houses and infrastructure.

CONCLUSIONS

High erosion zones are mostly related to rock falls in vertical road cuts and to the transport of loose sediments. Most erosion is located on the Intermediate to Low erosion areas over the Zacatecas Red Conglomerate which is moderate to loosely consolidated. This combination favours land subsidence and instability.

The erosion zones defined in this work are a tool for the urban development planning. The areas here defined are an argument to be considered in the land-use change policies in order to have a better use of territory.

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