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Seismic controls on contemporary sediment export in the Siret river catchment, Romania

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ABSTRACT

While differences in catchment sediment yield (*SY*, [t km^{-2} y^{-1}]) are generally attributed to topography, lithology, climate and land use, recent studies have highlighted that also seismic activity may have an important impact on *SY*. Nonetheless, relatively little is known about the importance of this factor and the processes and mechanisms explaining its influence. Therefore, this study explores the role of seismic activity in explaining spatial and temporal variation in sediment export within the Siret Basin (Romania, 45,000 km^2), a catchment with a large variability in seismic activity.

Based on previously unpublished long-term (>30 years) *SY* measurements for 38 subcatchments of the Siret, we analyze the correlation between average *SY*, seismic activity and various other catchment characteristics. Our results showed that spatial variation in average *SY* was indeed strongly correlated with the degree of seismic activity in each catchment ($R^2 = 0.74$). Also catchment lithology explained an important part of the differences in *SY* ($R^2 = 0.67$). The combination of these two factors accounted for about 80% of the observed variation in *SY*, while other factors (e.g. topography, land use, climate, and runoff) did not significantly contribute to the explained variance in average *SY*.

To explore the impact of a specific earthquake event on sediment export, we analyzed daily variations in suspended sediment concentrations of 10 subcatchments, five years before and after an earthquake of $Mw = 7.4$ that affected the Vrancea region in 1977 and triggered a substantial number of landslides. Only one catchment showed a clear (3-fold) increase in sediment concentrations at unit discharge. For the other nine catchments, no consistent increase could be observed. This indicates that the impact of seismic activity on average *SY* is mainly indirect and not associated with sudden pulses of sediments, caused by earthquake-triggered landslides. Potential mechanisms that could explain such indirect responses are discussed.

1. Introduction

Predicting sediment export by rivers is important for economical, ecological and geomorphic reasons (e.g. Owens et al., 2005; Syvitski and Milliman, 2007). However, the factors that control export rates are not yet fully understood. Hence predictions of sediment export at catchment scale are mainly based on empirical relations between measured sediment export rates and factors describing the topography, lithology, land use and climatic characteristics of catchments (e.g. Merritt et al., 2003; de Vente and Poesen, 2005; de Vente et al., 2013). Tectonic activity is generally not accounted for by these models, as it is (often implicitly) expected that eventual effects of tectonic activity on erosion and sediment fluxes are sufficiently represented by the topography of catchment (e.g. Milliman and Syvitski, 1992; de Vente and Poesen, 2005; Syvitski and Milliman, 2007; de Vente et al., 2013).

A growing number of studies show that this assumption is not always justified. Spatial variation in both long-term erosion rates (Portenga and Bierman, 2011) and contemporary catchment sediment yields (*SY*, [t km^{-2} y^{-1}]) are often strongly correlated with the degree of seismic activity within the catchments, even in regions with a relatively limited degree of seismic activity (Dadson et al., 2003; Vanmaercke et al., in press). Also after correcting for auto-correlations between topography, seismic activity remains a significant predictor of erosion rates or *SY* (Portenga and Bierman, 2011; Vanmaercke et al., in press). Several mechanisms may explain this effect. Earthquakes may trigger landslides, resulting in a direct increase in sediment export (e.g. Keefer, 2002; Dadson et al., 2004; Hovius et al., 2011). Secondly, seismic activity may cause rock fractures, leading to an increased susceptibility to erosion (e.g. Molnar et al., 2007; Koons et al., 2012). Furthermore, the occurrence of earthquakes is often correlated with tectonic uplift, which may result in river incision

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and hence increased sediment output at the catchment scale (e.g. Whittaker et al., 2010; Larsen and Montgomery, 2012).

The relative importance of these different mechanisms and the overall importance of seismic activity for *SY* in general are currently poorly understood. Our insight on these matters can be improved by detailed studies on the relationship between seismic activity and sediment export. However, few such studies are currently available and either provide only a regional analysis of the relationship between seismic activity and average *SY* (e.g. Portenga and Bierman, 2011; Vanmaercke et al., in press) or focus only on catchments with an exceptionally high degree of seismic activity and large relief (i.e. mainly in Taiwan; e.g. Dadson et al., 2003, 2004; Hovius et al., 2011; Huang and Montgomery, 2012).

In a recent study, Hovius et al. (2011) explored the effects of the *Mw* 7.6 Chi-Chi earthquake in Taiwan on the sediment export by rivers near the epicenter. They observed that the period after the earthquake was followed by a period of enhanced mass wasting and fluvial sediment evacuation. Sediment export peaked to more than five times the background rate but returned progressively to pre-earthquake levels in about six years (Hovius et al., 2011). However, Huang and Montgomery (2012) argued that it is very difficult to unambiguously relate these increases in sediment export to earthquake-triggered landslides, as also the occurrence of typhoons or extreme rainfall events may provide a plausible explanation. They further suggest that the earthquake had only a relatively limited impact on *SY* of their studied catchment. Higher sediment concentrations were only observed during low-flow events but not during higher flows (Huang and Montgomery, 2012). Studies exploring the effects of earthquake on temporal changes in *SY* for other regions are currently lacking.

This study therefore aims to better comprehend the relationship between seismic activity and *SY* and the mechanisms behind this relationship. This is done by investigating factors controlling *SY* and the evolution of sediment export for catchments with different degrees of seismic activity in and near the Vrancea region (Romania). The specific objectives are: (i) to analyze the spatial correlation between average catchment *SY* and seismic activity for catchments in and near the Vrancea region; and (ii) to evaluate the potential effect of a large ($Mw = 7.4$) earthquake on the temporal variation of sediment export for a number of catchments at varying distances from the epicenter.

2. Study area

This study focuses on subcatchments of the Siret river (45,000 km^2; Fig. 1), which drains the central to eastern part of the Eastern Carpathians, Eastern Sub-Carpathians, Moldavian Plateau and The Siret Lower Plain. The study area is part of the Alpine–Carpathian orogenic belt, resulting from the convergence and collision of several micro-plates (Moesian–Valachian micro-plate, Black Sea micro-plate, Inner Carpathian micro-plate) with the Eurasian plate during the closure of the Tethys Ocean (Airinei, 1977). The geological structures of this region are the result of the subduction process of the East-European plate (Eurasian plate), Moesian–Valachian micro-plate and Black Sea micro-plate under the Inner Carpathian micro-plate (Airinei,

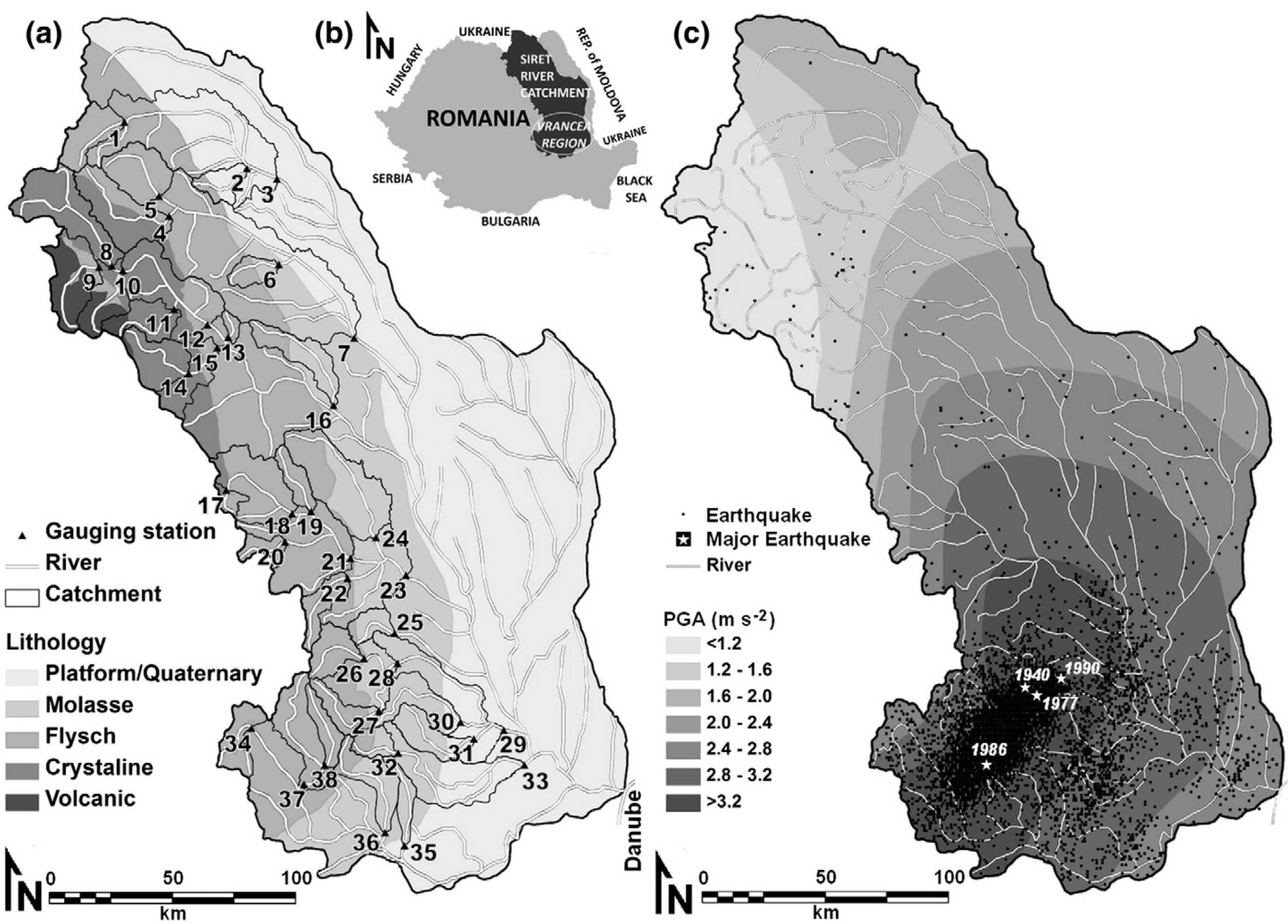

Fig. 1. Map of the study area. a) Subcatchments of the Siret basin ($n = 38$, see also Tables 2 and 4) of which sediment yield observations were used in this study. Numbers correspond to those of Table 2. Gray shadings indicate major lithological units. b) Location of the Siret basin within Romania. c) Seismic activity in the Siret basin. Gray shadings indicate the expected peak ground acceleration (*PGA*) with a recurrence interval of 100 years (Lungu et al., 2004) Superimposed are all earthquakes with a magnitude (*Mw*) of 0.5 or higher, registered between 1900 and 2010. Stars and their corresponding years indicate the epicenters of major earthquakes indicated in Table 1.