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Drainage reversal revealed by geomorphometric analysis of fluvial terraces

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Abstract— **Fluvial terraces preserve the paleo-profiles of rivers, recording the spatial and temporal changes of the landscape, and are key landforms in the study of river processes, active tectonics and paleoclimatology. In this paper we use an original mapping of different re-incised fluvial terraces, focusing on their attitude, to investigate the modification of flow direction of the Puglia River, a tributary of the Tiber River, in central Umbria, Italy. To obtain the attitude of the fluvial terraces, we start from the linear signatures of terrace edges mapped on aerial photographs and transferred into a GIS after raster tracing of the orthorectified image. Then, we build on a previous work aimed at obtaining bedding attitude information from bedding traces on the topographic surface, testing the capability of the method to provide information on the attitude of fluvial terraces. Results indicate the systematic dip toward SE of the highest terraces, while the lowest terraces dip to the W, in the same flow direction of the present-day Puglia River course. We interpret the results as the evidence of the southeastward flow of the ancient Puglia River, before bedrock incision, drainage inversion and deposition of the lowest terraces. We suggest a tectonic control as the main factor driving incision and river inversion in the landscape evolution of the area. We conclude encouraging the use of the same work flow to investigate fluvial related landforms elsewhere, in order to identify space/time changing of fluvial processes in diverse geologic, tectonic, and climatic setting.**

I. Introduction

Modification of rivers and their drainage basins is a poorly understood process associated with tectonically and/or climatically induced erosion, that strongly influence paleogeography, sediment budgets, and provenance. Such events may represent the geomorphological response to variation in rate, style, and locus of tectonic deformation, hence their identification and investigation is a key issue in active tectonic studies.

However, the reconstruction of ancient river systems is often hampered by the scattered distribution of rare and poorly preserved outcrops of fluvial sediments, a condition that undermines adequate stratigraphic and sedimentological studies, and requires the integration of geomorphological and morphometric investigations. In this contribution, we present a geomorphological e morphometric workflow aimed at identifying and measuring Earth surface changes related to the modification of rivers path and flow direction in an active extensional tectonic setting.

II. Methods

Based on multi-scale interpretation of stereoscopic aerial photographs, we identify and map a system of fluvial terraces associated with the evolution of the Puglia River, a tributary of the Tiber River, in central Umbria, Italy (Figure 1). This involved the interpretation of two sets of stereoscopic pairs of aerial photographs: panchromatic, taken in 1955 (1:33,000) and colors, taken in 1977 (1:13,000). Thematic information was drawn manually on transparent plastic sheets placed over the older photographs (Figure 2a). Then, the geomorphological information was transferred into a GIS using a semi-automatic procedure designed to reduce mapping errors (Santangelo et al., 2015). The procedure consists in the ortho-rectification of the aerial photographs and in the subsequent raster tracing of the geomorphological elements portrayed on the image (Figure 2b). The procedure exploits the GRASS GIS script i.ortho.photo, which requires a number of input data, such as the scanning of the aerial photograph and the superimposed undeformable plastic film, a DEM, an orthophoto map, and the camera parameters of the aerial photograph (Rocchini et al, 2010). The output vector features are stored in different thematic shapefiles.

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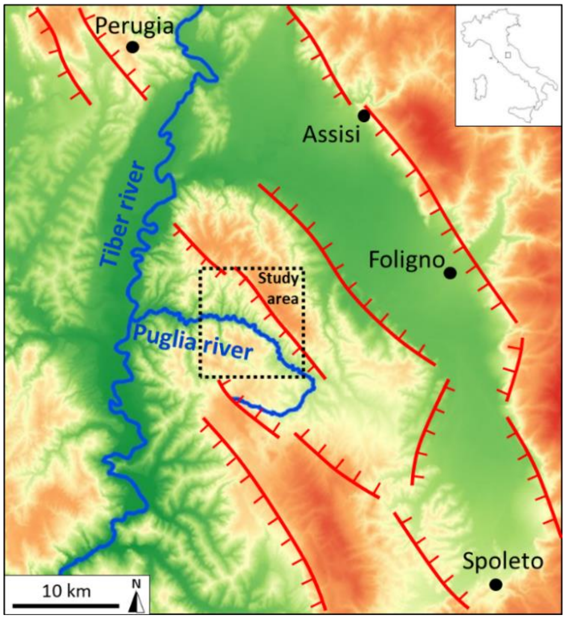

Figure 1. Location map of the study area in central Umbria, Italy. Main cities are indicated for easier geographical location. The area is crossed by the Puglia river, a tributary of the Tiber river. Map-scale main Quaternary normal faults with a clear morphological expression are also shown in red.

Among the others, we selected the fluvial terraces shapefile and we applied an open source processing chain that, starting from the aerial photo-interpreted boundary of fluvial terraces and the same DEM used for the orthorectification, produces a vector map of terraces attitudes. We define the terraces surface attitude as the combination of aspect and dip of the terraces surface. It has to be intended as the definition of bedding attitude. The procedure bases on a GIS tool, geobed.py (Marchesini et al., 2013), implemented using python in GRASS GIS environment and GNU-Linux OS. The geobed.py tool was developed in first place to reconstruct the attitude of bedding planes in layered terrains, and requires a bedding traces map and a DEM to be executed. In this contribution, we extend the application of the geobed.py tool to the reconstruction of the attitude of the fluvial terraces, hence a map of outer and inner edges of fluvial terraces were used in the place of the bedding trace map. The script iterates five steps for each terrace edge, and returns a point vector map containing information on dip angle, dip direction, and associated uncertainty. In the first step, the terrace edge is transformed into a 3D linear feature using the DEM. Secondly, the terrace edge is closed into a 3D polygon. Thirdly, a sequence of regularly spaced points is generated on the polygon boundary. A 3D Delaunay triangulation (Davis 1990) is then performed which outputs a nearly flat surface corresponding to the terrace surface. The slope and aspect raster maps of the terrace surfaces are then computed (step four).

Lastly, the mean values of slope (dip angle) and aspect (dip direction) of the terrace surface are estimated. The uncertainties of dip angle and dip direction are computed as (i) the standard deviation of the terrace slope map and (ii) as the circular variance (Davis 1990) and angular standard deviation (Butler 1992) of the terrace aspect map.

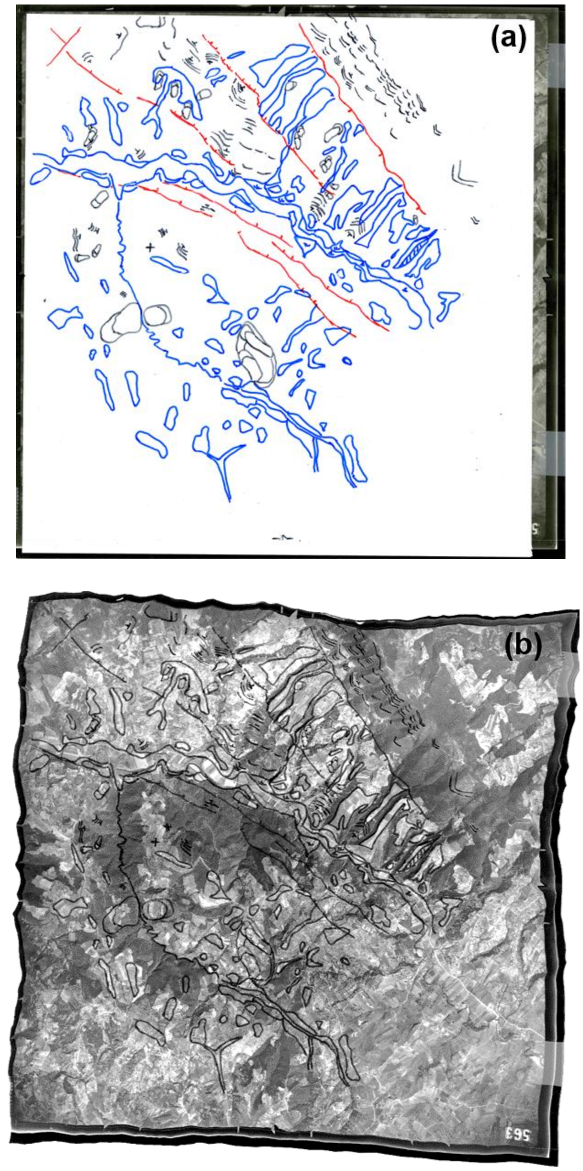

Figure 2. Thematic information drawn over the photograph. Different colors indicate different elements: red for faults, blue for terraces and alluvial deposits, black polygons for landslide, black lines for bedding traces (a). Orthorectification of the aerial photograph and the interpreted elements (b).

III. Results and conclusions

Results indicate the general S-SE oriented dip direction of the highest terraces, while a roughly W-SW oriented dip direction, consistent with the present-day flow direction of the Puglia River and its right tributaries, results for the intermediate terraces. The lowest terraces generally converge toward the main river course as evidence of the contribution of the lateral streams to the terraces building (Figure 3).

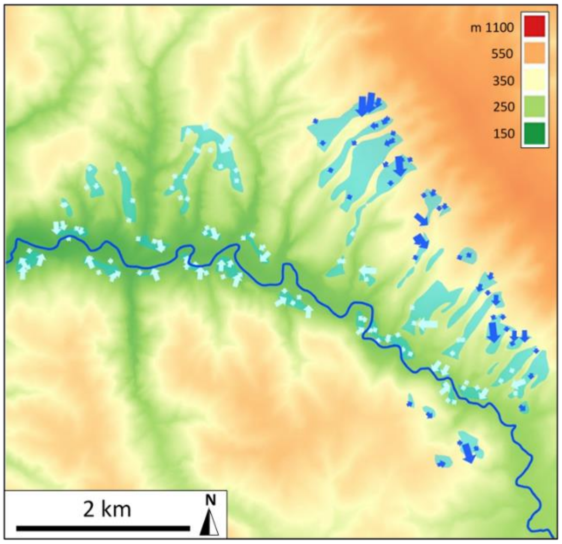

Figure 3. Main result of the analysis indicating different attitudes for terraced mapped at different elevations. Ciano polygons indicate the mapped terraces; blue arrows indicate the attitude of terraces located at highest elevation; light blue arrows indicate the attitude of terraces located at lower elevations and close to the present-day river course. Arrows size is inversely proportional to data uncertainty, measured as the angular standard deviation of the computed attitude values.

We interpret the results as the evidence of the southeastward flow of the ancient Puglia River, before reversal and deposition of the progressively lower terraces. Scattered sedimentological evidences, including pebble imbrication, composition, dimension and roundness, seems to confirm that the Puglia River reversed its course to westward flow in the recent geological past. Basing on an updated geological survey (Bucci et al., 2016) and original photo-geological information (Figure 2a), we document the structural control operated by normal faults on the geometry of the ancestral Puglia River Basin and propose that the drainage inversion was driven by progressive extension, consisting with an eastward migration of the normal fault activity. River reversal likely followed stream capture in response to enhanced fluvial erosion and uplift of the Puglia River basin, at the footwall of the NE dipping active normal fault bounding westward the Foligno Valley (Figure 1) (Mirabella et al., 2018). Future dating of the river terraces will allow determining the timing of the inversion of the Puglia River, and will help to constraint the space-time migration of fault activity. The findings are important in a more general perspective because open at the possibility to apply the same open source processing chain to detect, measure and model space/time changing of fluvial processes elsewhere, which in turn can be related to changing in rate, style, and locus of tectonic deformation, benefiting active tectonic studies.

References

[1] Bucci, F., Mirabella, F., Santangelo, M., Cardinali, M. & Guzzetti, F. (2016). Photo-geology of the Montefalco Quaternary Basin, Umbria, Central Italy. Journal of Maps, https://doi.org/10.1080/17445647.2016.1210042

[2] Butler R.F. (1992). Paleomagnetism: Magnetic Domains to Geologic Terranes. Blackwell Scientific Publications – Boston. Oxford. http://www.geo.arizona.edu/Paleomag/book/.

[3] Davis J.C. (1990). Statistics and data analysis in geology, 2nd edn. John Wiley & Sons, Inc, New York

[4] Marchesini I., Santangelo M., Fiorucci F., Cardinali M., Rossi M., Guzzetti F. (2013). A GIS method for obtaining geologic bedding attitude. Margottini, C., Canuti, P., Sassa, K. (Eds.) Landslide Science and Practice, Volume 1: Landslide Inventory and Susceptibility and Hazard Zoning, ISBN 978-3-642-31324-0

[5] Mirabella, F., Bucci, F., Santangelo, M., Cardinali, M., Caielli, G., De Franco, R., Guzzetti, F. & Barchi, M.R. (2018). Alluvial fan shifts and stream captures driven by extensional tectonics in central Italy. Journal of the Geological Society. https://doi.org/10.1144/jgs2017-138

[6] Rocchini, D., Metz, M., Frigeri, A., Delucchi, L., Marcantonio, M., and Neteler, M. (2010). Robust rectification of aerial photographs in an open source environment, Computers Geosci., 39, 145–151, doi:10.1016/j.cageo.2011.06.002, 2011.

[7] Santangelo, M., Marchesini, I., Cardinali, M., Fiorucci, F., Rossi, M., Bucci, F., and Guzzetti, F. (2015). A method for the assessment of the influence of bedding on landslide abundance and types, Landslides, 12, 295–309, doi:10.1007/s10346-014-0485-x, 2015b