Holocene stratigraphy and land subsidence: Understanding the subsidence of the Volturno River alluvial plain by combining geological and geotechnical modelling

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Session: Mechanisms and Understanding of land subsidence

Introduction

Recently most of the world's major river deltas are sinking due to both accelerations in global sea level rise and subsidence rates. Other effects of subsidence can be aquifer salinization, inundation of lowlands, and coastal erosion, among others (Bagheri-Gavkosh et al., 2021; Herrera-García et al., 2021). In coastal and delta areas, subsidence can have natural causes related to the recent formation and composition of the geological substrate. The latter is often consisting of alternating layers of sand and more compressible materials, like clay and peat.

In the Mediterranean area, there are several alluvial coastal plains affected by subsidence (Yan et al., 2020). The aim of the present study is the definition of the substrate architecture and its correlation with the ground deformation trends of an alluvial coastal plain along the eastern Tyrrhenian Sea. The study area is the plain of the Volturno River, located in the northern Campania coastal area (Southern Italy), developed after the Holocene transgression.

In this area the base of the Holocene deposit is represented by a volcaniclastic unit (the Campania Grey Tuff - CGT) originated by the Campi Flegrei caldera 39 ka eruption, that covered all the previous marine-transitional settings on the whole alluvial and coastal plain. In response to the Last Glacial Maximum sea-level drop, a paleovalley originated from the paleo-Volturno River fluvial downcutting, about 15-20 km wide and up to 30 m deep in the depocenter (Ruberti et al., 2022).

Materials and methods

The reconstruction of the subsoil relies on more than 1500 shallow borehole stratigraphies (mostly up to 20-30 m in depth) and CPTs located along the Volturno plain. The facies analysis and the lithostratigraphic study allowed the reconstruction of the Late-Pleistocene-Holocene stratigraphic architecture; moreover, the 3D graphic restoration of the LGM incised valley morphology, engraved in the CGT deposits, provided the outline of the reference surface for the Holocene sedimentation. The litho-stratigraphic data were compared with the coefficients obtained from the elaboration of CPTs, in order to characterize also the geotechnical properties of the different layers.

The next step involved a preliminary correlation between subsidence rates and the geological and geotechnical composition of the subsurface. A cumulative vertical ground displacement map was used, estimated during 1992-2010, based on Matano et al., 2018 (Fig. 1A).

In order to understand if and how the different lithologies recognized are related to the distribution of subsidence rates, post-CGT deposits were further classified and gathered on the basis of the main lithological facies such as sands, clays and peat as they represent the more compressible materials and subjected to secondary consolidation. For each stratigraphic log, the thicknesses of these lithologies were compared to the total thickness of the post-CGT deposit. Different coefficients were developed and hierarchized to establish the relationships between the analyzed characteristics of geotechnical weak horizons and the variability of subsidence rates, that range between 0 and -20 mm/yr in an area of about 750 kmq across the Volturno River and that shows places with apparently anomalous localized subsidence.

The overlay with data on settlements, road and rail networks and floodable areas represents a first step towards a risk analysis.

Results and discussions

Among the main outputs of the research, the reconstruction of the upper surface of the CGT is of valuable interest. It provides the picture of the palaeomorphology at the LGM through a 3D Digital Surface Model (DSM). The reconstructed surface actually suggests the occurrence of a complex network of incisions that supports the reconstruction of a channel entrenchment on the plain and especially towards the coastline, which at that time was located ca. 13 km offshore (Ruberti et al., 2022). Above this surface, large remobilization of volcaniclastic material took place during the re-establishment of the fluvial system, witnessed by the abundance of reworked pyroclastic ash and clasts recognized in the alluvial deposits of the medium-upper part of the valley fill. Transitional and marine deposits occur in the lower and coastal plain. There, medium-coarse sand and gravel intercalate to silty sand and grey-blue clay and silt very rich in organic material and peat (Fig. 1 C).

The spatial analysis, conducted by a GIS software, highlighted the relationship between major ground deformation and the filling of the incised paleo-valley, corresponding to the Holocene alluvial/transitional deposits that overlies a compaction-free Pleistocene basement, and this is consistent with the hypothesis that compaction of deeper Holocene strata is still significant (Fig. 1 A). Inside this general trend, differential compaction was detected proceeding from the coastal zone towards the interior (Fig. 1 B). This can be explained given the more recent age of the sediments in the inner part of the plain, the ones corresponding to the maximum ingression of the sea during the Holocene transgression. This can be confirmed by the consideration that most of the compaction of peat, in fact, occurs during the formation phase, mainly due to microbiological and chemical processes in wet environments. Thus, the deepest peat deposits (the oldest ones) have already compacted in the first stage of the Holocene transgression (van Asselen et al., 2009).

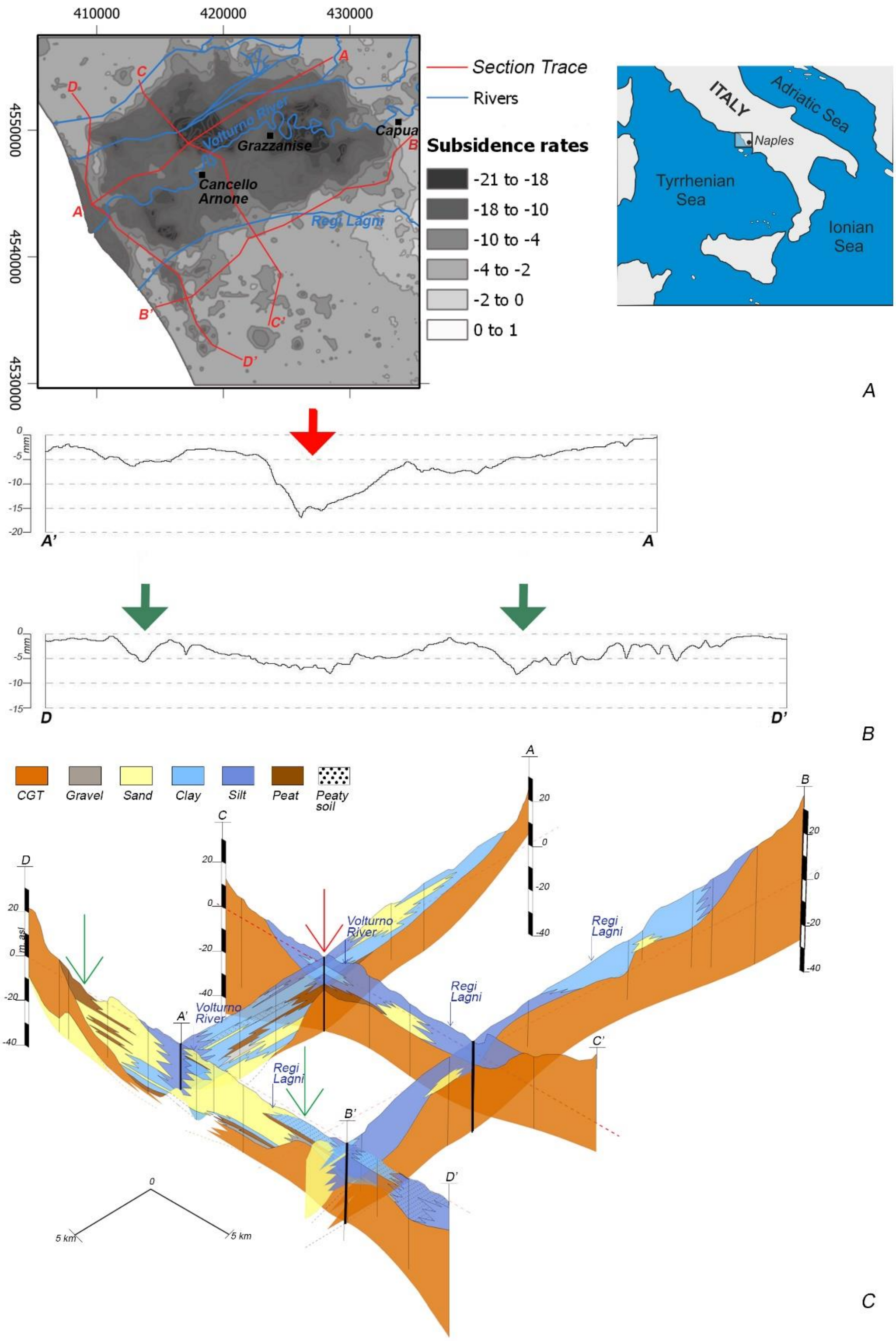

Figure 1 A) Cumulative vertical ground displacement map estimated during 1992-2010 (based on Matano et al., 2018). Location map of the study area. B) Subsidence profiles of the sections AA' and DD' are shown as representative of the general trend across the plain. Red and green arrows indicate negative peaks, discussed in the text and displayed on the 3-D lithostratigraphic reconstruction in (C).

Rates of subsidence due to the compaction of Holocene sediments have been documented in several floodplains and deltaic coastal plains around the world (Higgins, 2015; Teatini et al., 2011), due to the compaction of compressible sediments such as peat and clay. It is clear that compaction does not occur equally throughout the stratigraphic sequence, but may depend on stratigraphic position (i.e. age and depth) or thickness

Our findings confirm that the viscous component of these materials plays an important role in their behavior: the geologically younger soils are still subject to secondary subsidence while the older ones have already undergone much consolidation also because of the lithostatic load, and the inclusion of a significant amount of peat and organic matter clearly reflects high values for the coefficient of secondary compression.

In this respect, in order to characterize the geomechanical behaviour of each horizon, a detailed reconstruction of the Holocene fill appears to be of fundamental importance.

Conclusion

The analysis of the relationship between ground deformation and stratigraphic architecture have demonstrated the strong correspondence major vertical displacements and high thicknesses of compressible materials. Furthermore, the stratigraphic position of these layers assumes a significant role since the consolidation is time-dependent (Buffardi et al., 2021). With the aim to sharing research results, the future goal could be to export the methodology developed in this study to other coastal contexts in the Mediterranean area.

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