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Characterization of alluvial aquifers by multiscale hydrostratigraphic interpretation of DC resistivity data

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The characterization of aquifer heterogeneity plays a key role for the 3-D modelling of conductivity (K) distribution in the subsurface of alluvial plains. DC methods such as Vertical Electrical Soundings (VES) and Electrical Resistivity Ground Imaging (ERGI) yield respectively the 1-D and 2-D resistivity (ρ) distribution in the ground and are often applied in hydrogeology because ρ is controlled by the prevailing process of current conduction ("shale" vs. electrolytic conduction) determined by the occurrence of fine-grained sediments and saline groundwater.

Assuming that the sedimentary heterogeneity can be described with hierarchical elements at different scales (from hydrofacies to hydrostratigraphic systems) and recalling that the resolution of DC surveys decreases with depth, we propose an interpretation of the subsurface ρ distribution as a function of the hierarchical properties of aquifers (i.e., the vertical trends of facies with prevailing "shale" or electrolytic conduction) with hydrostratigraphic constrains. A correlation between ρ and pore-fluid saturation and chemistry permits the use of resistivity as a "proxy" of facies stacking.

Our case-study is the Quaternary valley of palaeo-Sillaro extinct meandering river (Po plain, Italy). The local stratigraphy up to 80 m below ground surface consists of LGM sand-gravel point bar and channel bodies overlying: i) clay to fine sand aquitard of an Upper Pleistocene flood plain, ii) alternating gravel-sand aquifer bodies and fine sand to silty-clay drapes formed by Middle-Upper Pleistocene braiding to meandering depositional systems that developed above iii) a basal aquiclude of silty-clays.

To interpret 1-D resistivity models obtained by 89 VES collected with Schlumberger array (maximum half-spacing 300 m) over an area of 30 km^2, a Coarse-to-Fine (C/F) litho-textural ratio (particle size cut-off=0.30 mm) was used to classify hydrofacies. The variability of C/F was compared with the K and ρ values of hydrofacies, both in the unsaturated and the saturated zone. A local relationship between K and ρ was then established and used to identify i) a fine litho-textural association (C/F<1), with a prevailing "shale" conduction, low ρ and small K and ii) a coarse litho-textural association (C/F>1), with a prevailing electrolytic conduction, high ρ and high K. The electrical resistivity was then reclassified in terms of the prevailing hydraulic behaviour (low or high K units), taking into account the differences between the saturated and unsaturated zones.

A representation of the sedimentary heterogeneity and connectivity was obtained through the correlation of VES models by vertical polarity of electrical contrasts and lateral persistence of ρ values which led us to map geoelectrical bodies informally named electrostratigraphic units (EsUs). The EsUs are defined by horizontal variations of the vertical electrostratigraphic sequence and characterized by a thickness coherent with the principles of electrical equivalence and suppression. 3000 m of 2-D ERGI sections collected with Wenner-Schlumberger array (electrodes spacing 5 m) led us to a further characterization of the EsUs at metric scale up to 40 m b.g.s..

Shallow EsUs represent vertical variations of ρ related to the litho-textural contrasts at the scale of the hydrofacies, as a function of the proportion between fine and coarse textures within each sedimentary facies (C/F ratio). Deeper EsUs represent vertical variations ρ related to the litho-textural contrasts within an heterogeneous and hierarchically stratified medium at the hydrostratigraphic systems scale.