New Geophysical and Geological Modeling Approach in Mixed Siliciclastic-Carbonate Reservoir for Site Effect Assessment*

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Abstract

Theoretical and experimental site response studies show the strong impact of geological properties (surface geometry, facies and petrophysical properties) for the simulation of realistic ground motion, including source, regional attenuation and local site effects. It is then of paramount importance to better understand the geological uncertainties (complex surfaces geometries and facies distribution) for site effect assessment. In particular, major uncertainties concern the bedrock geometry of sites studied, which is often poorly characterized.

We focus our study on the Middle Durance region, which includes the Middle Durance fault and the Cadarache valley, local site of the CEA (French Alternative Energies and Atomic Energy Commission). We built two multiscale imbricate geological models, including the "site effect" part as well as the fault and the descriptions of the main regional geological formations for "rupture and regional attenuation part" of the future ground motion simulation.

Introduction

The geological substratum of Cadarache includes Cretaceous to Quaternary formations separated by three major unconformities. These formations result from a complex sedimentary history marked by the passage from a marine (lower Cretaceous) to a continental environment (Tertiary and Quaternary) interrupted by successive erosions. The resulting high heterogeneity of facies makes difficult the understanding of this complex sedimentary system. The 2D correlations of facies are difficult to visualize. That is why the high complexity of this sedimentary system needs to be unraveled in 3D considering the 3D structural framework and the facies distribution.

The available database used for this study includes a low and high-resolution geological and structural map (1/5000e), 15 deep drillings, more than 1,500 geotechnical wells, hundreds of H/V ambient vibration measurements, which could give information on the bedrock depth. This database is extremely heterogeneous from the quality and resolution points of view, especially concerning the sedimentary facies

description in wells. Therefore, we propose an original integrated workflow adapted to heterogeneous, huge and diverse database. In addition, this workflow includes the calculation of uncertainties such as the core description.

Model Development

We build a 3D sedimentary and structural model of the geological basement of Cadarache area. This "high resolution" model is 9 km x 7 km, and about 500 m deep and comprises planar as well as discrete data as follow: 1/ three major stratigraphic surfaces corresponding to synchronous times-surfaces: the tops of the Secondary, Tertiary and Quaternary formations, 2/ facies and geotechnical filling between the three major surfaces, based on geostatistical analysis, integrating uncertainties on the description and spatial repartition.

In a first step, we built a surfacic model (DSI) composed of three major unconformity surfaces: the Top-Quaternary, the Top-Tertiary and the Top-Secondary. The geometry of the Top-Mesozoic is constrained by geological maps, 1,225 boreholes and H/V profiles. In a second step, a 3D stratigraphic grid with a cell size of 10x10x2 meter conditioned to the three major unconformity surfaces was achieved in order to define the stratigraphic framework of the facies modelling. The stratigraphic grid is divided into 2 regions: Quaternary (118,101 cells) and Tertiary (1,078,968 cells). Borehole data are integrated in the grid. Finally, we applied a variographic analysis and pixel-based simulation with indicator kriging to simulate spatial facies distribution in 3D within Tertiary region.

Using H/V method allows identifying a high seismic velocity contrast boundary between the Cretaceous marine limestones (bedrock) and the Quaternary and Tertiary continental deposits (cover) of the valley. Ten H/V profiles have been realized perpendicular and parallel to the valley. Geological data (geological map, boreholes) and the bedrock depth from H/V profiles have been compiled with gOcad in order to recover the surface of the Top-bedrock beneath the Cadarache Valley (Figure 1).

Producing a ground motion simulation need to understand the 3D distribution of depositional facies, which control the reservoir properties such as porosity, permeability and seismic velocities. Based on the geological synthesis of 1,344 boreholes and on the geological map, we identified ten major geological facies occurring in the geological substratum of the Cadarache Valley. These facies have been simulated in Tertiary region (Figure 2).

We performed a variographic analysis on the boreholes crossing the Cenozoic region of the 3D stratigraphic grid and proceeded to 3D facies simulations. We obtained a 3D facies model for the facies distribution of the Cenozoic cover beneath the Cadarache Valley.

The results of the 3D model concern the bedrock geometry of the Cadarache valley and the sedimentary facies 3D spatial distribution of the Tertiary filling of the valley. Figure 1 shows a 3D view of the surface of the top bedrock (Lower Cretaceous limestones). This surface presents a steep paleovalley. This paleovalley is characterized by abrupt edges ranging from 15 to 25° and a narrow bottom with a slope of 10°. The orientation of the paleovalley ranges from NW - SE (upstream part) to NNW - SSE (downstream part). In the Tertiary filling of the valley, facies simulation (Figure 2) has shown that the sedimentary facies 3D spatial distribution is controlled by several parameters. The distribution of simulated clays and breccia facies is controlled by distance to the limestone bedrock. The most part of these facies is located close to the bedrock. It reveals also that presence of clays and breccia facies simulated increase with distance to the bedrock. Finally, the

proportion and lateral continuity of clays and breccia facies simulated are controlled by the geometry of the bedrock surface (width and slope). Geostatistical analysis of the boreholes data coupled with the study of the facies in outcrops and boreholes allows proposing a 3D model of the sedimentary tertiary filling of the Cadarache Valley. It reveals two-step sedimentation: the first is characterized by important detrital inputs from southeast, related to the dismantling of the massif of Maures-Estérel; the second is characterized by a sandy meandering fluvial deposits system with high sinuosity. Our study has highlighted various types of fluvial deposits and their spatial distribution: base of channel deposits, deposits of crevices in the collapse of the banks and floodplain deposits. During this period, fluvial deposits are periodically affected by terrigenous inputs of type colluvium from erosion of the slopes of the valley.

3D numerical modelling is an efficient tool to integrate a huge and heterogeneous database (1,344 boreholes, high-resolution geological and structural maps, H/V ambient vibration measurements and geological cross-sections) and better understand a complex sedimentary system. The 3D facies model of the cover of the Cadarache valley reveals a sandy meandering fluvial deposit model controlling the properties of the Tertiary reservoir. This depositional model is controlled by the Top-bedrock geometry (incised valley with sloping edges) and disturbed by important coarse (breccias) and fine materials (clays) from periodic inputs due to erosion and/or destabilization of the edges of the valley.

Summary

This geological model, performed in 3D, contributes significantly in understanding the physics of wave propagation in complex geological systems (mixed siliciclastic-carbonate systems). It gives 3D information on surface and subsurface geology (surface geometry and facies distribution) which is critical for ground motion simulations accuracy. In particular, we focus our geological and geophysical study on the bedrock geometry characterization of the Cadarache valley, composed by fractured Lower Cretaceous carbonates. By coupling boreholes data and H/V geophysical method, we determine the precise 3D geometry of the top of the Lower Cretaceous carbonates.

We aim to apply our approach (original database integrated workflow, 3D geological modeling with geostatistical analysis) to different sites, included in European research projects: the Volvi Basin in Greece (E2VP-2 project) and the Grenoble Quaternary valley (France).

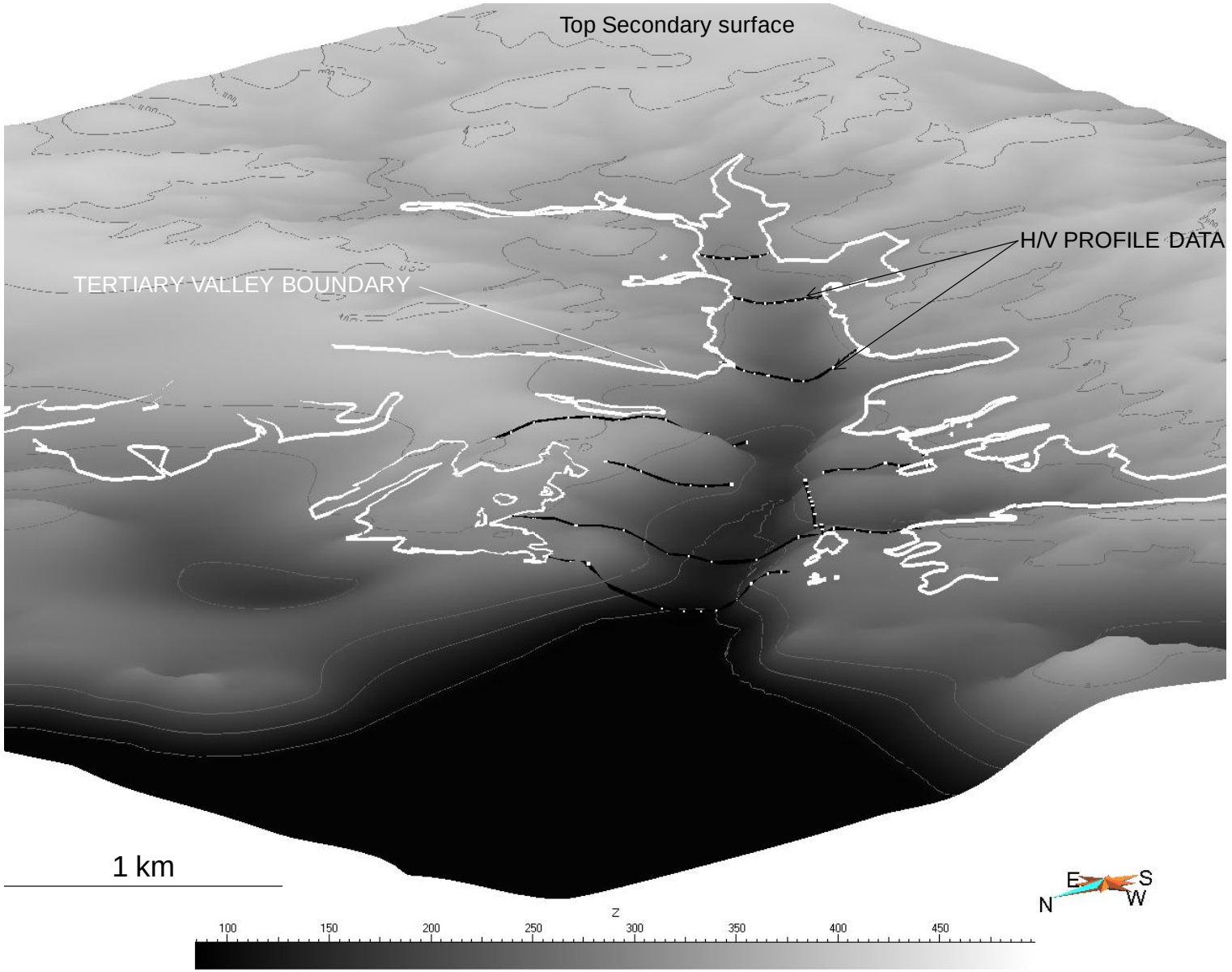

Figure 1. Geometry of the Top-bedrock beneath the Cadarache incised valley.

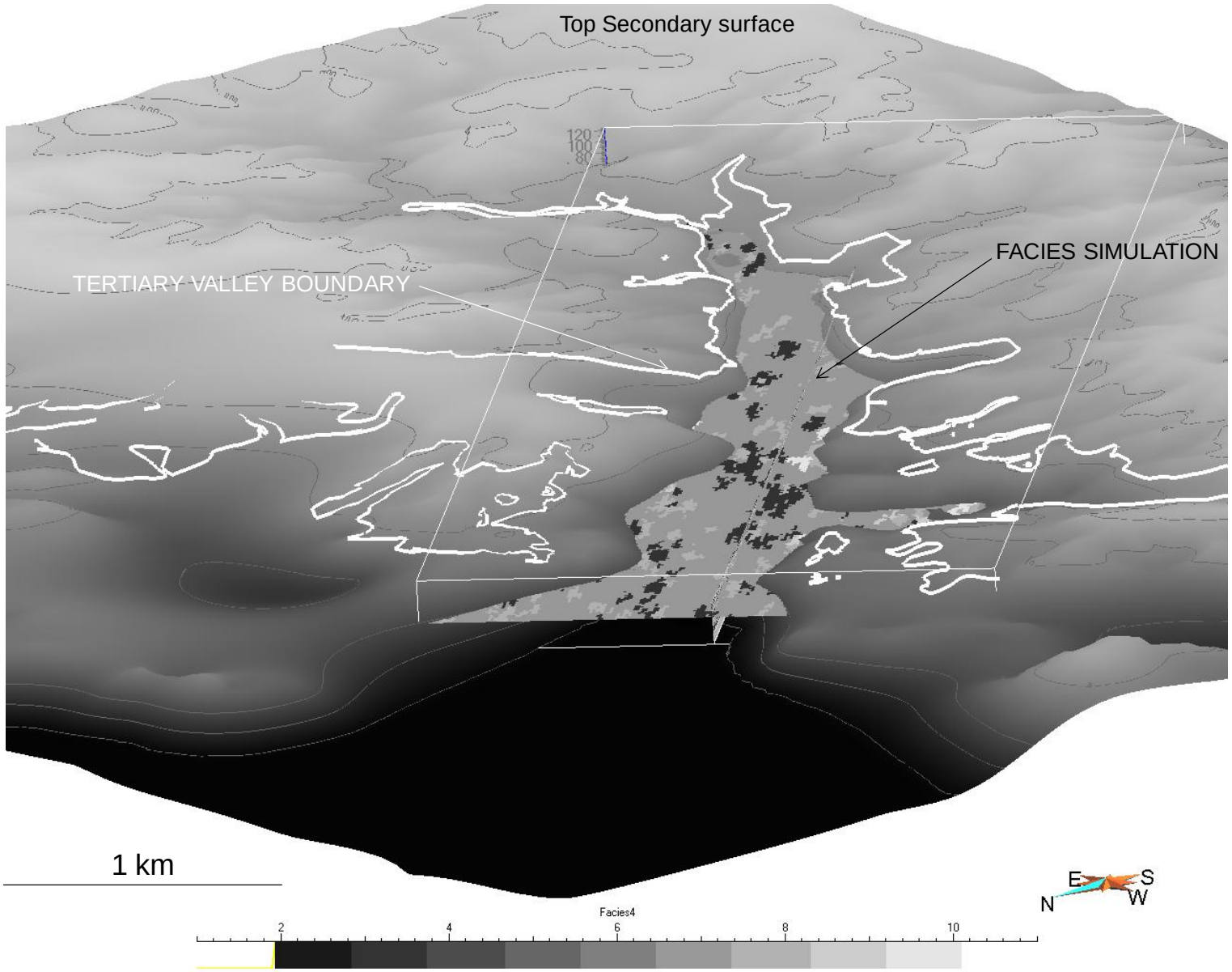

Figure 2. Facies simulation of the Cadarache incised valley.