

## Scientific drilling in the campus: Almera-1 borehole, unraveling urban subsurface geology in Barcelona (Spain).

### *Perforación científica en el campus: Almera-1 un sondeo para investigación del subsuelo urbano de Barcelona.*

M.J Jurado<sup>1</sup> and J.M. Salvany<sup>2</sup>

1 Instituto de Ciencias de la Tierra Jaume Almera, CSIC, 08028 Barcelona (Spain), mjjurado@ictja.csic.es

2 Dept. d'Enginyeria Civil i Ambiental, Universitat Politècnica de Catalunya, 08034 Barcelona (Spain), josepm.salvany@upc.edu

**Abstract:** Almera-1 borehole was drilled to provide a borehole geophysical logging and downhole monitoring research and training facility. Also a main objective was the exploration of the urban subsurface geology adjacent to the Institute of Earth Sciences Jaume Almera (CSIC) in Barcelona the University of Barcelona Pedralbes. Wireline drilling continuous coring was successfully applied to recover cores from the entire section (214m). Since 2011 Almera-1 hole has been extensively used for slim hole logging, coring and monitoring. Total depth was reached after drilling a Quaternary to Paleozoic section. The upper section of Almera-1 hole is cased with PVC and the lowermost is an open hole section within the Paleozoic section. A complete set of geophysical logging measurements and oriented borehole images was acquired with CSIC own slim hole logging equipment both in open hole mode and through the PVC casing. Logging measurements were acquired over the entire section. Open hole measurements included acoustic and optical imaging, spectral natural gamma ray, full wave acoustic logging, magnetic susceptibility, hydrochemical-temperature logs and fluid sampling. Through casing (PVC casing) measurements included spectral gamma ray logging, full wave sonic and acoustic televiewer.

**Key words:** scientific drilling, borehole geophysical logging, downhole monitoring, log interpretation.

**Resumen:** El sondeo Almera-1 se perforó con el objetivo principal de construir una infraestructura de investigación en el campo de la testificación geofísica de sondeos y la monitorización del subsuelo. Asimismo tuvo como objetivo la exploración del subsuelo urbano adyacente al laboratorio de testificación geofísica, ubicado en el Instituto de Ciencias de la Tierra Jaume Almera (CSIC), en el campus universitario de Pedralbes de la Universidad de Barcelona. La modalidad de perforación y recuperación continua de testigo con cable ("wireline") permitió optimizar la recuperación de testigos hasta los 214 metros de profundidad que alcanzó el sondeo. Desde 2011, el sondeo Almera-1 se ha utilizado para la investigación y experimentación con sondas geofísicas y la monitorización del subsuelo. El reconocimiento del subsuelo realizado ha permitido caracterizar una sección de 214m constituida por materiales atribuidos al Cuaternario en la zona superior y a partir de los 41 m de profundidad atribuidos al Paleozoico. Se reconocieron diversas litologías y facies, zonas de fractura y de falla, así como niveles karstificados y procesos diagenéticos. La caracterización geológica se ha llevado a cabo principalmente mediante la interpretación integrada de testigos y de perfiles geofísicos e imágenes orientadas adquiridas con el equipo de sondas de testificación geofísica del ICTJA que incluyen en sondeo abierto sondas de espectrometría gamma (U, Th, K), acústica de onda completa, susceptibilidad magnética, perfilaje continuo de fluidos con sonda hidroquímica y de temperatura y muestreo de fluidos, entre los más destacables, y a través de entubación con las sondas gamma espectral, acústica de onda completa y televiewer acústico.

**Palabras clave:** perforación científica, testificación geofísica de sondeos, monitorización del subsuelo, interpretación geológica de diafragmas.

### INTRODUCTION

Almera-1 hole (214m) was drilled in the University of Barcelona (UB) campus area adjacent to the ICTJA-CSIC building (Fig 1). This location is in a urban area in the Barcelona plain area and is covered mainly by Quaternary sediments. Almera-1 and Almera-2 holes were drilled with three main purposes: 1) to create a new research infrastructure for professionals and

students training, 2) to explore the subsurface geology, 3) to carry out geophysical logging research and monitoring experiments. A direct connection to the lab was built to facilitate long term measuring experiments to be controlled from the borehole research lab at ICTJA-CSIC. The upper section of Almera-1 hole was cased with PVC to preserve borehole stability and the lowermost section was left open at the time of drilling completion. In this study we present the results related

to the advance in the knowledge of the subsurface geology explored by scientific drilling at Almera-1. A second auxiliary hole, Almera-2 49 m deep was drilled to carry out cross-hole and tomographic experiments and hydrological monitoring.

Wireline drilling and coring was successfully applied and a good core recovery was obtained for compact rocks although poor core recovery in heavily deformed rocks (Fig. 2). Almera-1 borehole was logged in open hole mode (before casing) and also through the PVC casing on with specific logging tools (total and spectral gamma radioactivity through casing, acoustic televiewer, full wave sonic and magnetic susceptibility).



FIGURE 1. Location of Almera-1 borehole in the Barcelona Plain

## GEOLOGICAL SETTING

Almera-1 hole was drilled in the Barcelona Plain (Fig. 1), a Quaternary geomorphic feature between the Paleozoic Collserola range and the Quaternary recent sediments of the Llobregat and Besòs deltas. The Barcelona Plain sediments were deposited on a heavily structured pre-Quaternary lower to middle Miocene and Pliocene formations in the central and eastern part and directly on heavily structured Paleozoic rocks in the west of the Barcelona Plain (Fig. 3). The Collserola range, bounded by the Llobregat and Besòs river valleys, is made up (IGC, 2010) mainly by igneous (granitoids) and metamorphic rocks and also Paleozoic sedimentary rocks, terrigenous and carbonates (Fig. 3), from Ordovician to Carboniferous in age (Julivert i Duran, 1990). These rocks were strongly deformed during both the Variscan and also the Alpine orogeny. These rock units are faulted by NE-SW trending normal faults and progressively deepen towards the SE (Fig. 3).

The Llobregat and Besòs deltas are made up of detrital sediments mainly of Holocene age, and are locally covered by a layer of silty redish sediments up to 10m thick originated from reworked older Quaternary sediments (Fig. 3). Another striking feature

is the fault system, roughly parallel to the coast related to the extensional phase that shaped the Mediterranean Western margin (Bartrina et al., 1992). This system was active mainly during lower Miocene. Llopis Lladó (1942a) reported activity during the Quaternary. The latest movements and activity along these faults favoured the formation of thick Quaternary deposits at the toe of the range of Collserola range (Sarrià-Les Corts zone Fig. 2). Minor faults and folds were described that deform the oldest Quaternary sediments (Llopis Lladó, 1942b), suggesting reactivation of these structures under compression. The Tibidabo and Turons faults (Fig. 3) form the structural boundary between the Collserola range and the Barcelona Plain. Between both faults Paleozoic metamorphic and sedimentary rocks are outcropping, to the North of the Barcelona Plain (Santanach et al, 2011). To the south these rocks are covered by ancient Quaternary sediments as confirmed by previous drilling and at the Almera-1 drillsite.

## ALMERA-1 SUBSURFACE GEOLOGY: GEOPHYSICAL LOGGING AND CORE DATA

Almera-1 borehole was drilled into Quaternary sediments of the Barcelona plain (Fig.1.), in the area between the Tibidabo and Turons fault (Fig. 3). Quaternary sediments were recovered in the uppermost section (0-41m) and Paleozoic rocks from 41m to total depth (T.D.) at 214.1m (Fig.4). Drilling revealed a significant gap at the drillsite corresponding to Tertiary sediments. Two geological units can be characterized on the basis of both the geophysical log response and also core description (Fig.3, Fig. 4): a Quaternary section consisting of poorly consolidated detrital sediments and a lower Paleozoic unit made up mainly by black and grey slates, carbonates and metamorphic rocks. At 41m a Paleozoic section consisting of tectonized rocks was reached. From this depth to (T.D.) different Paleozoic units and lithofacies were drilled (Fig. 3). By correlation with outcrops in the Collserola range Almera-1 Paleozoic rocks would include Devonian, Silurian and possible Ordovician age rocks.



FIGURE 2. Core of Paleozoic rocks recovered.

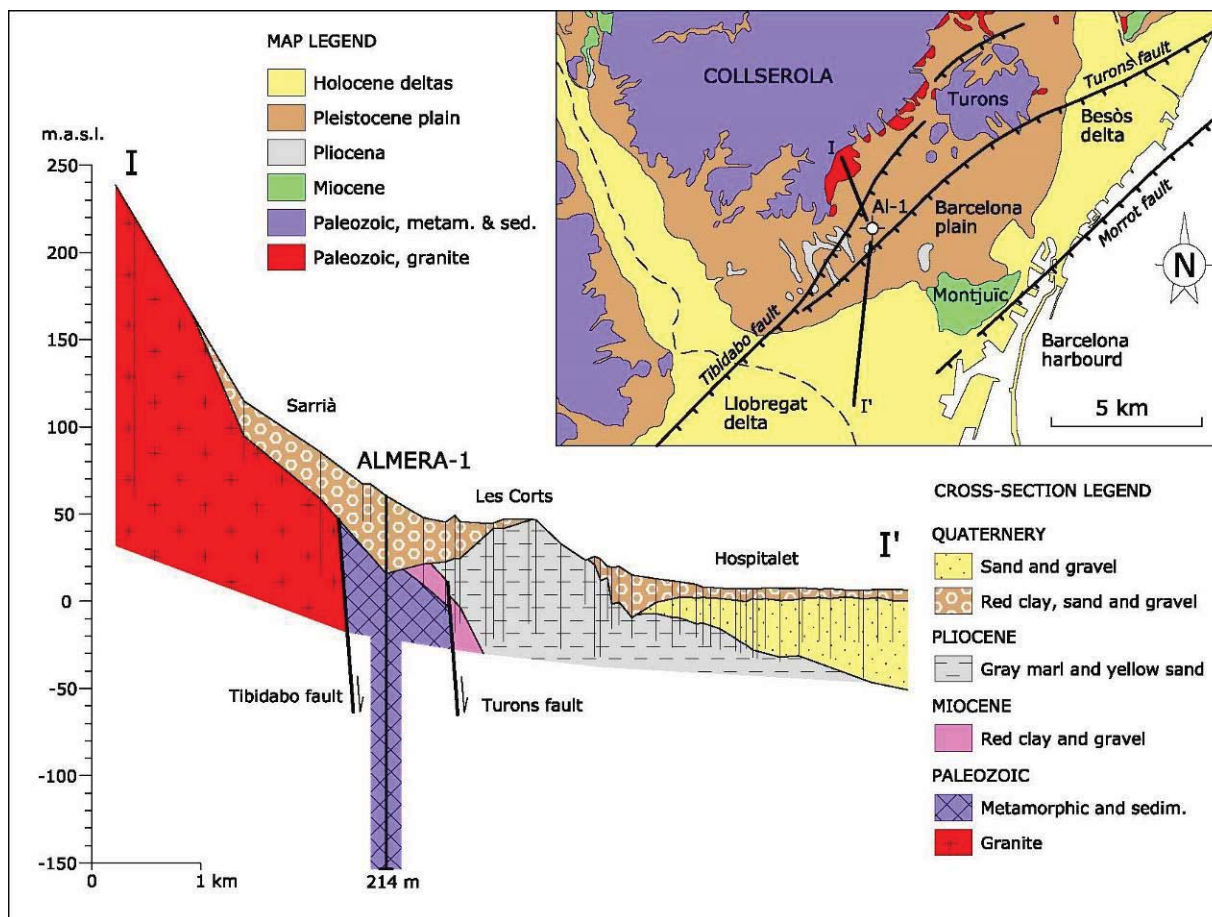


FIGURE 3. Schematic cross section showing the position of Almera-1 borehole. Vertical lines indicate borehole geology of previous drilling analyzed by Salvany.

Oriented borehole images acquired with optical and acoustic viewers were applied to measure bedding orientation, fractures and faults orientation and also to characterize diagenetic and textural features. Geophysical logs display changes that are related to lithological, compositional and textural changes identified and characterized on cores (Fig. 4, Fig.5). An example of gamma ray log and of correlation of gamma ray values with lithological changes and boundaries is shown on Figure 4. Another example (Fig. 5) illustrates how lithological and compositional changes are shown on acoustic viewer borehole images, gamma ray and sonic logs and correlation to cores and core lithological description.

Both logging data and borehole images and core descriptions indicate the existence of different lithofacies within the Paleozoic section. By correlation with neighbouring outcropping sections these may correspond to Devonian and Silurian and eventually also Ordovician at T.D.. Nevertheless in the absence of precise and specific datings of these rocks, these age assignments remain uncertain. Structural interpretations of viewer borehole oriented images allowed us to define different deformation phases within the Paleozoic section and the existence of fault zones,

folds, karstification and diagenetic processes that are being analyzed in detailed studies.

## CONCLUSIONS

Almera-1 borehole provides new data to define the subsurface geology in a urban area. Quaternary sediments overlie unconformably weathered, deformed and locally metamorphic Paleozoic rocks. A gap of Tertiary rocks at the drillsite is confirmed. Interpretation of geophysical logging data borehole oriented images and core analyses have been successfully applied to define the stratigraphy and structures at the Almera-1 borehole. Structural features were defined based on oriented images interpretations.

## ACKNOWLEDGEMENTS

The Faculty of Geology of the University of Barcelona for collaboration in this initiative. Almera-1 and Almera-2 holes were drilled by Geotec-262. M.J. Jurado research supported by PNIDI- CGL2009-13405, CGL2010-21568, and ACI2008-0773 projects. Techlog (Schlumberger) licenses were used for log and image interpretation of borehole images and geophysical logs. Albert Ventayol is acknowledged for advice and suggestions.



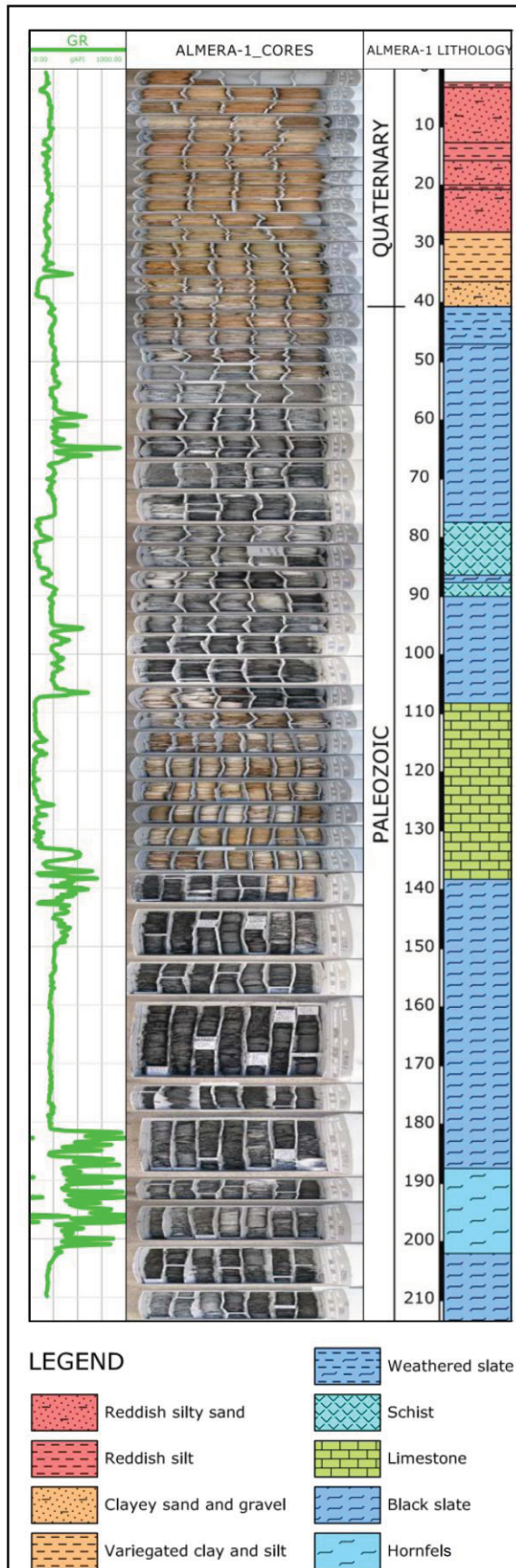


FIGURE 4. Gamma ray, core box images and lithology based on core descriptions.

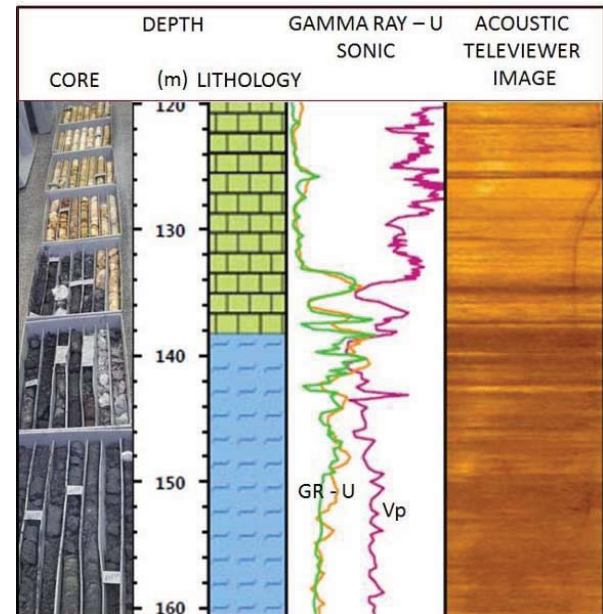


FIGURE 5. From left to right: Almera-1 core boxes, core lithology, total and spectral uranium gamma ray sonic logs and, in the last track televiewer image. All data showing the lithologic change between Devonian carbonates (low gamma and spectral U, high sonic velocity, good ultrasonic amplitude reflectivity) and black slates (higher gamma and spectral U, lower acoustic velocity, less ultrasonic amplitude reflectivity).

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