Hydrogeological Research and Mine Design to Prevent the Impact of the Future Integrated Lithium Project "San Jose de Valdeflórez Project" to "El Calerizo" Aquifer (Cáceres, Spain)

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Abstract

This article describes the methodologies and results of the site characterization work carried out to define the substrate of both the underground exploitation and surface facilities areas of the San José de Valdeflórez Project (the Project) and the main mine design measures developed to prevent affections to "El Calerizo" karstic aquifer. The hydrogeological and hydrogeochemical research programme has allowed the formulation of a Conceptual Hydrogeological Model and the definition of its main parameters.

Keywords: Site characterization, unsaturated zone, low permeability, karstic aquifers.

Background and objectives

The San José de Valdeflórez Project (Cáceres, Spain) seeks to conduct a rational and sustainable exploitation of the Valdeflórez lithium deposit, integrating technical innovations and social sensitivities to guarantee its acceptance and mitigate risks. Geologically and hydrogeologically, is in the Cáceres Syncline. The Armorican and Silurian quartzite outcrops draw the North and South flanks. Both have been the object of mining exploration and exploitation, mainly for tin and phosphates, in the last century.

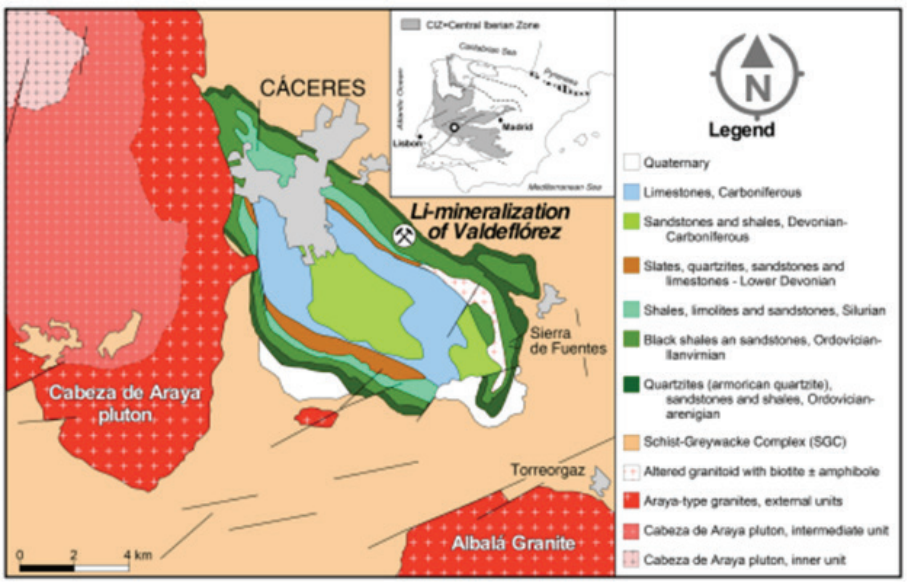

Figure 1 Simplified Geological setting (Pesquera et al.*, 2020).*

The northern flank forms a narrow valley between two quartzite ridges, in the middle of which an Ordovician psammopelitic sequence (Valhondo unit) hoists the Li deposit. In between the psamopelites it appears, interlayered, quartzite levels in which Li-rich quartz-micas and Quartz and greisen type veins are the main Li sources (Pesquera *et al.*, 1999, 2020).

Hydrogeologically, it is an impermeable to very low permeability environment. The Li deposit, which outcrops on the surface, extends to at least 450 m deep, has been exhaustively investigated through a detailed structural geological characterization, including more than 10,500 m of drillholes and the analysis of more than 4,200 samples, which has allowed the set-up of a geological model that has revealed a 111.3 Mt resource (indicated and inferred included) and an average grade of 0.61 wt% Li2O (JORC Resource), one of the largest in Europe. (*Pesquera et al.*, 2020).

Methods

Valdeflórez mining complex is in two hydrogeological units (U.H.-1 El Calerizo and U.H.-2 Valhondo) in the Salor and Guadiloba basins rivers, respectively. The mining exploitation works are in the U.H.-2 (Valhondo), on the northern flank of the syncline, while the tailings (TMF), treatment plant and other facilities will be located on the U.H.-1 (El Calerizo), also on the northern flank of the syncline. (Fig. 2).

For the study of the karstic aquifer, a specific hydrogeological and hydrogeochemical characterization program has been developed, starting by the establishment of the geological-structural model based on various field campaigns of controlled source geophysical techniques: Electrical boreholes, Microgravimetry, Electrical Tomography… A total of 4,000 m of Electrical Tomography profiles were done, in order to determine the thickness of the decalcification clays surficial layer and to make an assessment of the possible existence of karst cavities at depths of up to 15–20 m. These investigations have been complemented by an Audio-Magneto-Telluric Tomography (AMDT) campaign with a total of about 5,000 m, with the aim of studying the characteristics of the substrate up to 300 m deep and establishing the most favourable locations for the implementation of trenches and hydrogeological boreholes.

This has allowed the definition of the substrate geometry of both the unsaturated and the saturated zones of the karst aquifer in the Project area and its surroundings. The hydrogeological research program began with the water points inventory and sampling to determine their piezometric characteristics and chemical quality, and then the determination of hydrogeological parameters through specific "in situ" tests.

Results and discussion

Fig. 3 to 5 (*INGEMISA, 2024*) summarize the results of the piezometric measurements

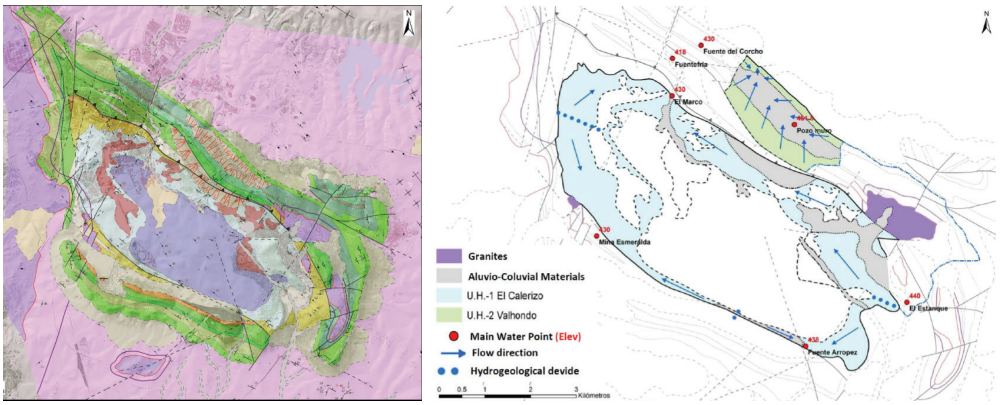

Figure 2 *Cáceres anticline Geological Map and Hydrogeological Units (INGEMISA, 2024).*

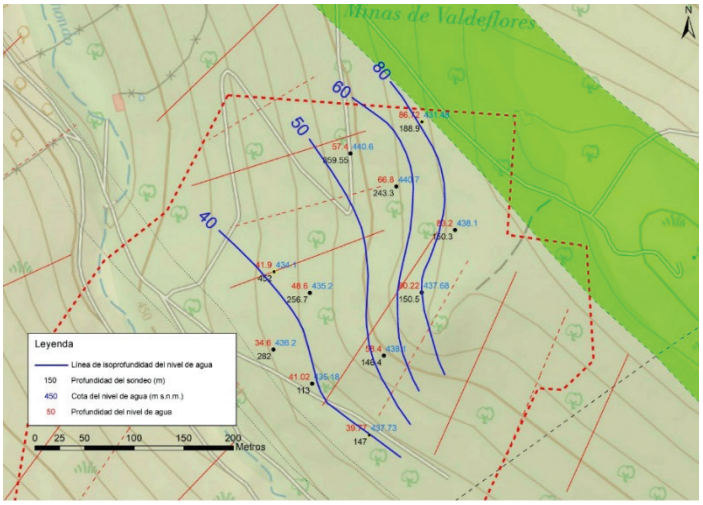

Figure 3 *Mining Area (UH-2. Valhondo Unit). Depths to the water table.*

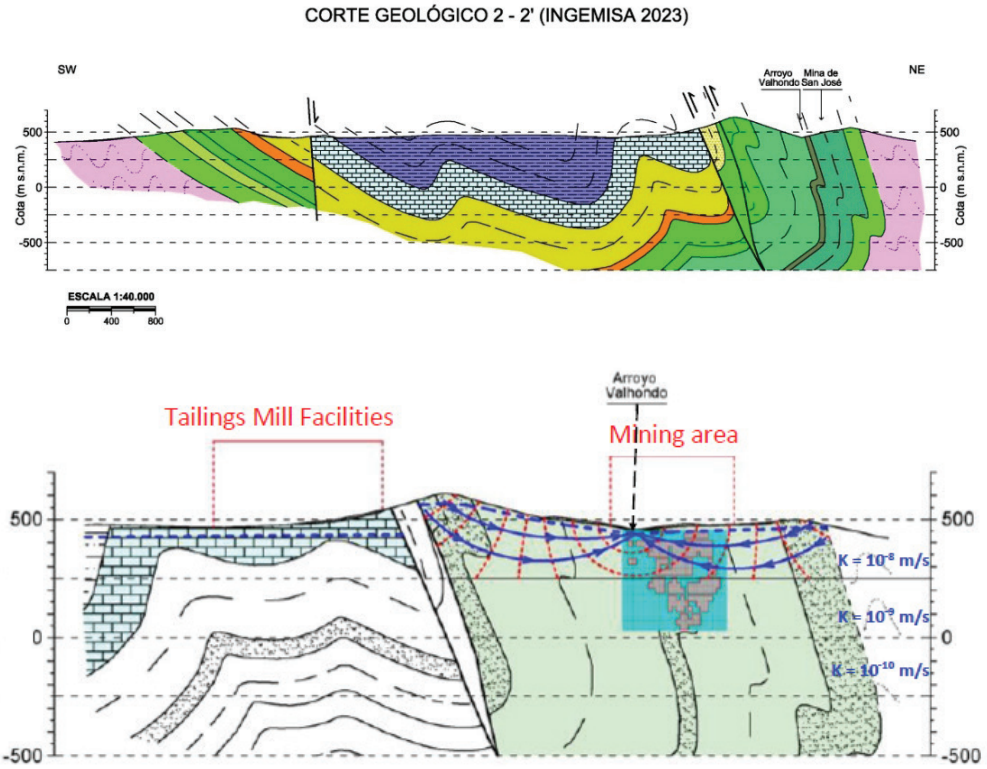

Figure 4 *Cross section (Fig. 2) and Hydrogeological Profile based in the Conceptual Model.*

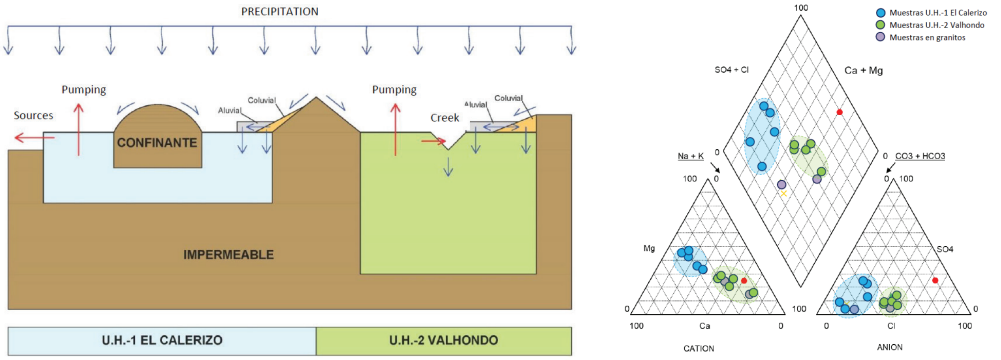

Figure 5 *Relationship between Hydrogeological Units and their hydrochemical character.*

in the mining area, a cross-section NE-SW and hydrogeological profile trough the mining and mill tailings areas, the conceptual model from them deduced, and a chemical quality diagram that shows the differences between the two hydrogeological units. As may be observed, both units (El Calerizo and Valhondo) are not hydraulically connected, as are separated by levels of slates and vulcanite of exceptionally low permeability that guarantee the individualization of their hydrogeological functioning.

The planned mining area is in the UH-2 (Valhondo), formed by a main aquifer of a multilayer type, permeable by mechanical fracturing and free regime, with local effects of confinement and marked anisotropy, both vertically and horizontally. Horizontal anisotropy is due to the different permeability of the different lithological layers of the aquifer. Permeability values between 10^{-9} m/s and 10^{-7} m/s are attributed, with the highest values corresponding to the fractured quartzite layers and the lowest to the shales. Intermediate values (K = 10^{-8} m/s) correspond to slates and quartzites intercalations. The average permeability of the unit in the exploitation area is in the order of K = $4{\cdot}10^{-8}$ m/s, compatible with a medium of low permeability. The depths of the wells inventoried in this area reach a maximum of 150 m, with variable flows between 0.1 and 0.2 L/s. The specific flow rate is estimated to be between 0.01 L/s/m and 0.02 L/s/m, so, the most frequent value for the transmissivity will be T = 0.1 to 0.2 m^2/d.

In the area planned for the Tailings Management Facility (TMF), treatment plant and other facilities, 4 pumping tests has been carried out, in which transmissivity values of less than 1 m^2/d have been obtained. In addition, two Air Lift tests have been conducted in two nearby boreholes, which yielded higher transmissivities: 16 to 100 m^2/d, values later confirmed by pumping tests. It is observed that, in the central and northern sectors of this area, the values of transmissivity and permeability are low, while in the southern sector they acquire higher values, compatible with the hydraulic characteristics attributed to the aquifer. This confirms the marked anisotropy of the environment and its compartmentalization into blocks of different hydrogeological characteristics. (Fig. 6).

For the investigation of the unsaturated zone of the substrate of the TMF zone, eleven "in situ" infiltration tests have been carried out on the decalcification clays that cover the carbonate outcrops, in trenches (Porchet and by the double ring methods). All of them were instrumented with pressure sensors in continuous sampling and with recording periods of up to 3 days. They show permeability values in a range of K = 10^{-7} m/s and K = 10^{-6} m/s. TDR and FDR (Time and Frequency Domain Reflectometry) have determined the moisture content.

Given that the average piezometric level of El Calerizo aquifer in this area is located at 35 m, the water flows that eventually reach the substrate under the decalcification clays

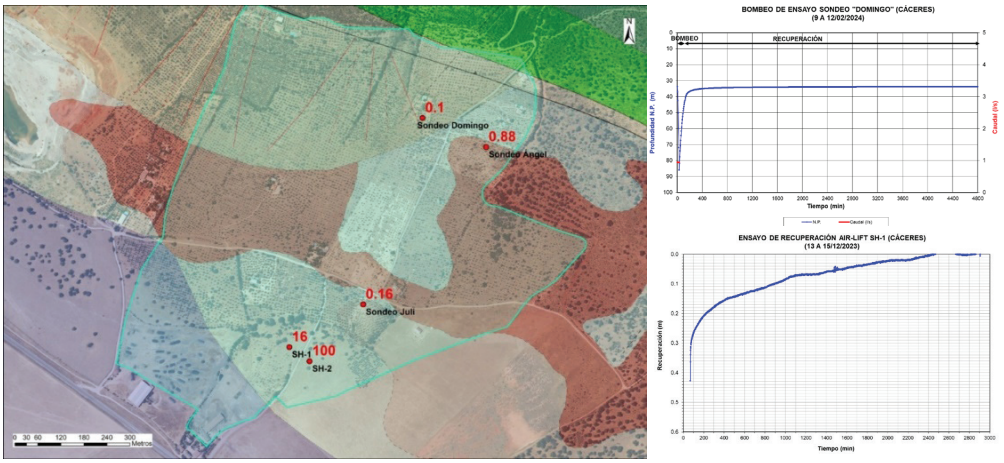

Figure 6 *Karst aquifer transmissivities (m2/d): pumping and air lift test diagramms (INGEMISA, 2024).*

would circulate through the unsaturated zone, until they reach the piezometric level, with a speed dependent on the permeability of the medium. For the values indicated above, transit times would be in the order of one year.

Mine design

The exploitation of the deposit will be carried out by the well-known underground mining method sub-level stoping, with paste backfilling. This mining method increases the ore recovery. The materials used for backfilling are the tailings produced in the processing plant, so the Project uses its own natural resources, minimizing the dependence on external materials. The stopes will be divided into primary and secondary, so that the secondary stopes will serve as a pillar while the stopes already exploited are filled with paste with a variable cement content, pumped with an optimum humidity that allows the flow through a pipe system but reduces the water consumption, afterwards, the secondary stopes are mined. The mine is divided into 60m height levels, subdivided in sub-levels. Each level is mined from the lower to the upper sub-level. Once a level is fully mined, and backfilled, the accesses not needed for mine services are closed for this level. The mine access will be through two ramps (services and transport), *Mining Sense Global (2024)*, (Fig. 7).

The geographical constrains for the mine facilities dictate that the project infrastructure is located to the South of the orebody. To

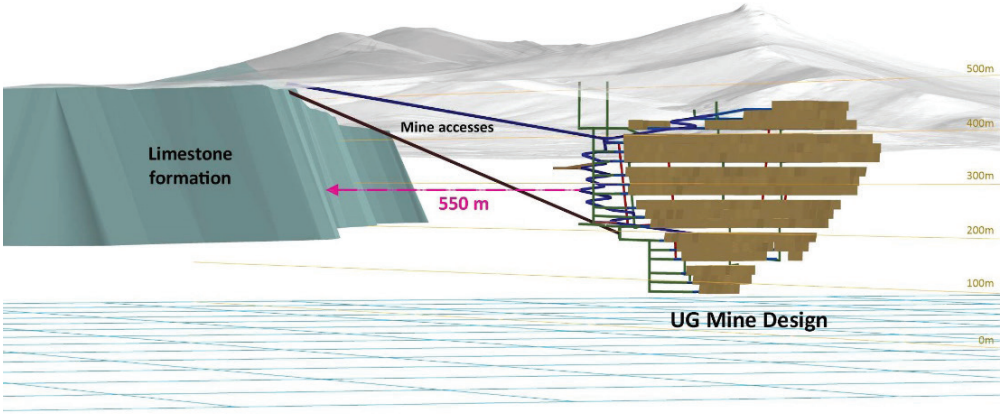

Figure 7 *Mine design (Mining Sense 2024)*

avoid that the mining works are developed through the Calerizo aquifer, the mine portal is to the North of the contact between the Calerizo limestone levels and the slate and vulcanic levels. Both, the galleries, ventilation shafts, and the exploitation area itself, are located in the low permeability materials that compose the U.H.-2 (Valhondo Unit), which has a hydrogeological behaviour independent of the El Calerizo aquifer. Mining works that need to be drained are, hence, developed on materials with low transmissivities and low affection to the surrounding users.

But the Valdeflórez Project has not only avoided to cross the lithologies in which El Calerizo aquifer is; in addition, a series of action protocols will be implemented, focused on:

1. Minimizing the impact of rock blasting in the vicinity of the excavation, and the development of secondary permeability due to fracturing.
2. "In advance" investigation, using geophysical techniques, oriented boreholes, and eventual sealing of fractures that may act as preferential pathways. In that sense the use of pre-grouting, where the investigation shows it appropriate, will have an important impact, with three main advantages: to control water inflow, to limit groundwater drawdown above the galleries, and to make tunnelling progress more predictable since rock mass quality is improved (*Barton et alia*, 2019).
3. Internal drainage system that guarantees that underground works are carried out in a drained environment, so that the water generated in the mine itself can never infiltrate outside the mine, as it acts as a sump during the exploitation phase.
4. Mine filling with low permeability paste material, to minimise the possibility of water contamination during the closure and post-closure stages.

Groundwater management will consist of the collection of water inflows and water produced by the mining works in pumping stations, provided by settling ponding compartments, to reduce solids. This water is pumped to the mine water deposit on the mine gate, from which the water is used back for mining works, the excess of water is used of other mining activities mainly for paste backfill, ore treatment of dust suppression. This makes the underground mining works self-sufficient in terms of water needs.

Conclusions and future research lines

In the San José de Valdeflórez Project a significant effort has been dedicated to the development and optimization of a mining and surface facilities design that allow the exploitation of the Li resources in a responsible and sustainable way. The characterization of the project substrate has been conducted, defining its geological-structural context based on surface geology, remote sensing techniques, application of various geophysical methods and borehole drilling.

The hydrogeological and hydro-geochemical research programme carried out has allowed the formulation of a Conceptual Hydrogeological Model and the definition of its main parameters. One of the most important efforts has been the definition of the unsaturated zone, where the surface facilities will be located and its role in the protection of El Calerizo aquifer, using Electrical Tomography, Infiltration tests, TDR & FDR, AMDT...

The integration of the available geological-structural and hydrogeological information in a calibrated hydrogeological model, with predictive capabilities, together with the Groundwater Control Network drilling program, will allow, through their instrumentation and monitoring, to continue the performance assessment of the facilities to demonstrate that they do not affect the evolution of El Calerizo aquifer through appropriate measurements and sampling.

This investigation will be continued during the construction phase, by the implementation and integration of protocols focused on the reduction of impacts, both, on the water drawdown impact, ground stability, water inflow and work progress prediction, taking the control measures in the case of deviations.

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