El Berrocal (Spain)

Description: El Berrocal is an area approximately 100 km south west of Madrid close to Toledo in Spain. The site and the analogue study take their name from the El Berrocal granite which forms a large hill. The granite is in the south-western part of the Spanish Central Massif, close to the south-eastern extent of the Sierra de Gredos and the Tertiary Basin of the Tajo River. The granite contains a number of small, vein-hosted uranium ore bodies which have been exploited but are now abandoned. One of these ore bodies was the focus of the analogue investigations. This ore body had previously been mined and a number of underground tunnels had been closed. However, one horizontal adit was still open and this allowed the granite and some veins to be characterised at depth.

Figure 1 shows a cross-section of El Berrocal with the arrows showing the general direction of groundwater flow.

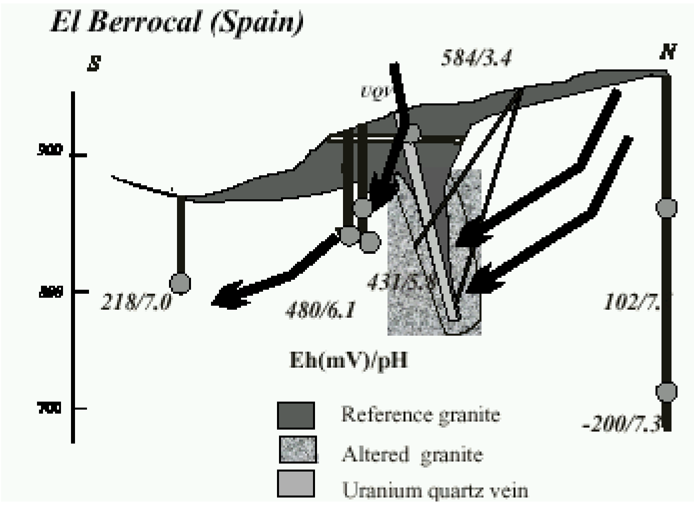

Figure 1 A cross-section of El Berrocal. Eh/pH data are shown in the approximate positions of the sampling boreholes (from Bruno et al.).

The El Berrocal granite has a uranium content that averages 16 mg/kg, with primary uranium occurring as accessory uraninite dispersed in the granite matrix. Post emplacement hydrothermal alteration mobilised uranium, thorium and rare-earth elements from the granite and re-deposited a proportion of them in a large, 2 m wide, steeply dipping quartz vein. Uranium-series disequilibrium data indicate that this hydrothermal mobilisation event occurred more than one million years ago.

Erosion and weathering is exposing the vein-hosted mineralisation, causing further elemental mobilisation and transport. The El Berrocal project had the objective of investigating these present-day, low-temperature mobilisation processes as well as the processes responsible for elemental retardation in the granite.

In particular, the study investigated:

- uranium mineral stability, degradation and dissolution;
- uranium solubility and speciation;
- blind predictive testing of a number of different geochemical codes and databases for Ba, Cu, Pb, Mn, Ni, Sr, Th, U and Zn;
- matrix diffusion of U in the rock adjacent to fractures; and
- colloid-associated radionuclide transport; the filtration of colloids was found to be effective (Rivas et al., 1997).

In addition to these analogue studies, a great deal of other work was undertaken to develop techniques and methodologies to allow the site to be characterised in detail in terms of geology, mineralogy, geochemistry and hydrogeology. This work included diverse studies such as detailed structural and mineralogical studies, hydrogeological measurements, tracer tests and microbiological investigations (Figure 2).

Figure 2 The El Berrocal site with the mobile geochemical laboratories for analysing the borehole water samples (from Miller et al., 2000).

The results from the project indicated that mobilised uranium and thorium tended to be associated by sorption and co-precipitation with certain fracture coating minerals, notably iron oxyhydroxides and calcite. Enrichment of uranium by a factor of up to 6 was observed, and up to 3 for thorium, relative to the fresh granite. Considerable effort was made to understand these co-precipitation processes in order to improve thermodynamic models and databases for performance assessment.

The El Berrocal project has been described widely in a number of publications. The most detailed are a four volume report series (ENRESA, 1996) and a final summary report (Rivas et al., 1997). Key results from the investigations include the finding that mobilised uranium is mainly associated by sorption and co-precipitation with fracture-coating minerals, especially calcite and iron oxyhydroxides (Pérez del Villar et al., 1997).

Relevance: Information from the El Berrocal study was used to test PA geochemical modelling capability and methodology. The study was used as an opportunity to improve site characterisation techniques for granite sites and for training personnel in the use of these techniques. The EC-funded work was focussed on the role of colloids and rock matrix diffusion.

Position(s) in the matrix tables: crystalline rocks, advection, diffusion, colloids, chemical retardation.

Limitations: The exact geochemical composition of the fluids that produced the hydrothermal mobilisation event to redistribute uranium and other elements is not known.

Quantitative information: Hydrogeochemical data for a variety of different groundwaters from the El Berrocal site were applied in blind predictive modelling tests of solubility and speciation (ENRESA, 1996; Rivas et al., 1997). A summary account of these extensive modelling exercises can be found in Miller et al. (2000). The results help to improve thermodynamic data for barium, copper, manganese, nickel, lead, strontium, thorium, uranium and zinc and to improve our understanding of in-situ co-precipitation processes. These geochemical modelling studies highlighted the need to include co-precipitation in geochemical models for PA work in order to achieve a closer realism to nature (Smellie et al., 1997).

The hydrogeochemical/geochemical test cases from the El Berrocal study can be usefully used again for testing new codes and thermodynamic databases (e.g. Pate et al., 1994).

Data on the matrix diffusion of U are available, although the processes that occurred at El Berrocal are probably a complex combination of matrix diffusion and water-rock interactions (Heath, 1995). The data nevertheless demonstrate an effective immobilisation of U in the rock matrix after migrating from the flowing fracture.

Uncertainties: The in-situ speciation data of some of the dissolved trace elements have high degrees of uncertainty. Nevertheless, the geochemical data are of high quality, overall.

Time-scale: The El Berrocal analogue deals with a geological time-scale, with the main processes of concern covering the Quaternary (<2 Ma).

PA/safety case applications: The geochemical data have been used to test geochemical modelling capabilities for PA work (e.g. ENRESA, 1996).

Communication applications: Used in some ENRESA literature. A brochure on the project was produced (see Synthesis Report).

References:

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Added value comments: The need to incorporate co-precipitation processes in PA is certainly a major output of this analogue study. However, the present state of the art and knowledge on co-precipitation processes (particularly for several important fission products like Se, Tc, Zr, Mo, Ni) is not sufficient and a gap till exists in order to provide the relevant co-precipitation models and data to PA assessors. Filling this gap requires some basic research to be conducted on co-precipitation processes together with natural analogue guidance.

Potential follow-up work: The site may be too sensitive with the local population to revisit for further in-situ speciation experiments. Further work on existing geochemical databases is of interest: this is why the availability of these databases to the scientific community through website facilities or on electronic media is important.

Keywords: far-field, granite, nuclide solubility, nuclide sorption, nuclide migration, matrix diffusion, colloids, uranium, redox, coprecipitation.

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