Osamu Utsumi Mine (Brazil)

Description: The Osamu Utsumi Mine study formed part of the Poços de Caldas Natural Analogue Project carried out from 1986 to 1990 (Chapman et al., 1992) and sponsored by SKB, Nagra, UK DOE and the US DOE. The mine is located in a ring structure or caldera of Mesozoic age comprising a suite of alkaline volcanic and plutonic rocks (phonolites and nepheline syenites) containing variable amounts of U, Th and REEs (Figure A). The site had been already the subject of prior scientific interest being one of the first economically exploited uranium mines in Brazil.

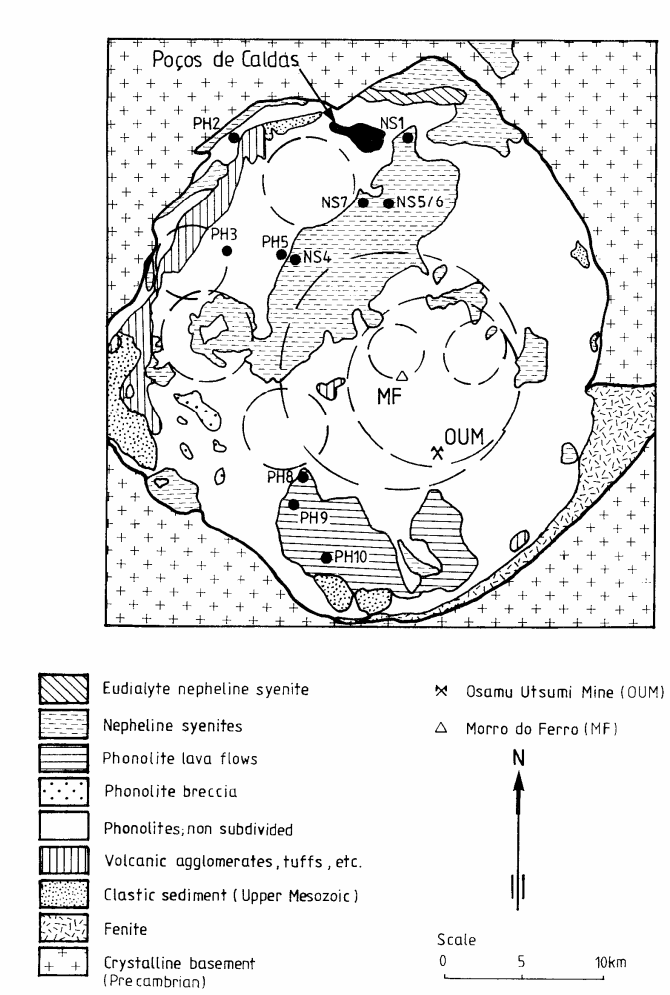

Figure A: *Simplified geological map of the Poços de Caldas caldera showing the major rock types and the location of the Osamu Utsumi mine.*

Studies at the Osamu Utsumi mine itself, and to a much lesser extent within the caldera as a whole, clarified the complex geological interrelationships between:

- the primary magmatic/deuteric episode resulting in the emplacement of rocks with enhanced backgrounds of uranium, thorium, zirconium, molybdenum and REE's;
- the post-magmatic regional hydrothermal alteration of the caldera complex giving rise to argillisation and zeolitisation of the rocks, together with some remobilisation of uranium, thorium and REE's;
- the localised hydrothermal events which have remobilised and concentrated uranium, thorium and the REE's (together, for example, with molybdenum and zirconium) mainly as stockwork breccia mineralisations, some of economic potential;
- the development of deep weathering profiles and the formation of supergene uranium remobilisation deposits (as pitchblende) at and adjacent to migrating redox front systems. This has resulted in further argillisation of the rocks, together with small-scale remobilisation of REE's and other trace elements in association with the redox fronts.

Interpretations of the site were further influenced by the extensive mining excavations which extended the groundwater discharge area, such that bedrock which originally received downward percolating oxidising waters now receives upward discharging reducing waters (Figure B).

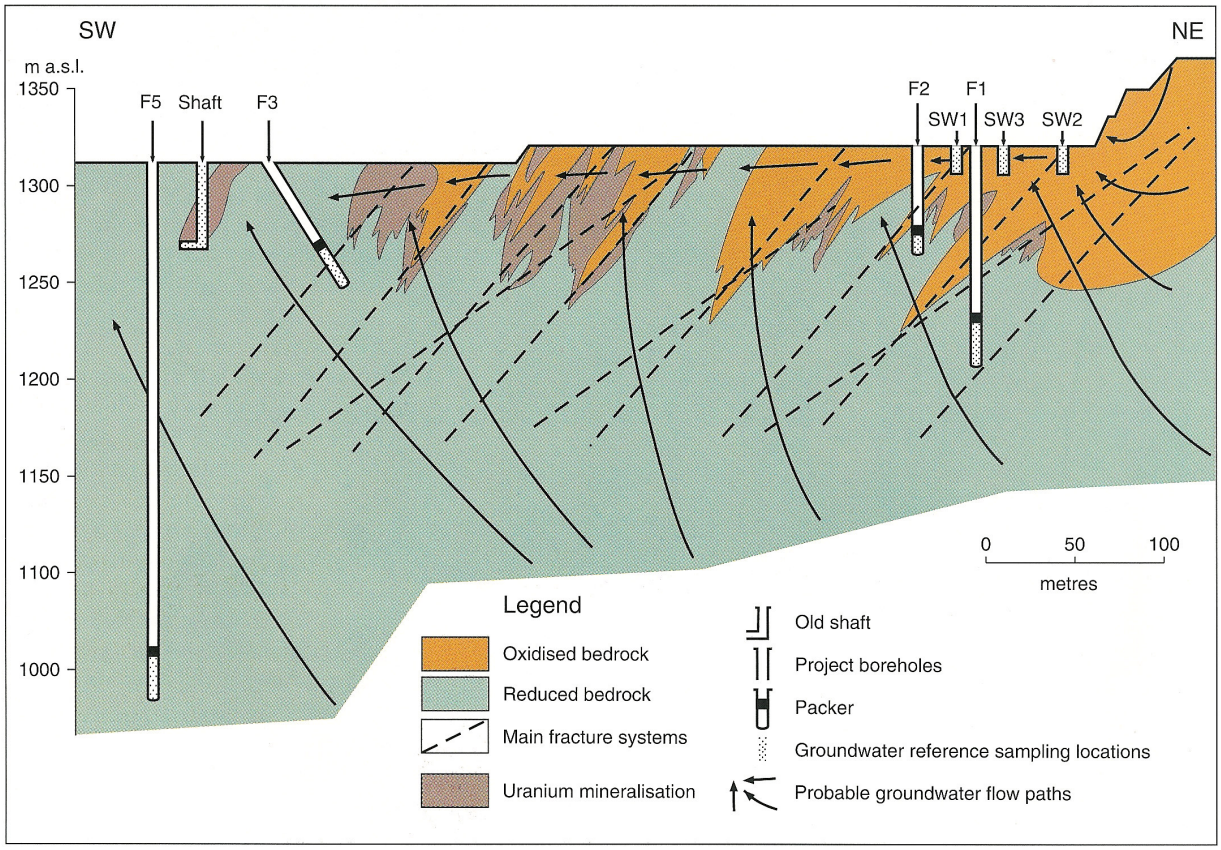

Figure B: *Cross-section of the Osamu Utsumi uranium mine showing the location of the boreholes, the redox fronts, the major areas of reduced/oxidised bedrock, and probable flow directions of the modern groundwaters (after Nagra, 1993).*

In general, the groundwaters are of unusual dilute composition and indicate intensive weathering from actively circulating fresh groundwaters in contact with the highly leached potassic-rich rockmass. As a result, the waters are essentially of K-Fe-SO_4 character. Oxidation of pyrite (dispersed throughout the reduced bedrock) due to the mixing of reducing discharge waters and near-surface oxidising waters within the upper 50m of the mine bedrock, has produced acid mine water at and near the surface. At greater depths the groundwaters are more reducing in character and some redox trends are indicated. Tritium and stable isotopic data support the present groundwater flow model.

Geochemical model computations reveal that the dominant processes are the production of CO_2 (by aerobic decay of organic material in the soil zone, and/or, by anaerobic microbial activity at depth), the dissolution of fluorite, calcite, K-feldspar, albite, manganese oxides, oxidation of pyrite and sphalerite, and the precipitation of ferric oxides, silica and kaolinite. These results are supported by mineralogical observations.

The three major technical objectives from studies at the Osamu Utsumi mine were: 1) To test geochemical equilibrium thermodynamic codes and databases used to evaluate rock/water interactions and the solubility/speciation of trace elements; 2) To test models of the geochemical evolution of redox fronts specifically aimed at understanding their role in influencing long-term, large-scale movements of redox-sensitive natural series radionuclides; and 3) To model the migration of REEs and U-Th series radionuclides during hydrothermal activity similar to that anticipated in some repository designs.

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Relevance: Irrespective of disposal concept, geochemical models are used in all performance assessments; the Osamu Utsumi Mine provided the opportunity to rigorously test these models resulting in improvements to the relevant thermodynamic databases. For example: a) the unlikelihood of ^{V}U species, b) solubility of Th was lower than expected, c) pure phase solubility control on co-precipitation is conservative, and d) being able to omit high temperature ferrite phases. With respect to redox fronts: a) the formation and movement of the redox fronts could not be modelled which underlined the inadequacy of the coupled codes used, b) despite the identification of several processes and mechanisms, the overall complexity of the geochemical system resulted in no clear understanding of radionuclide retardation, and c) microbially mediated reactions have played a role in radionuclide retardation. Hydrothermal studies, at the time relevant to the US disposal design, are no longer valid as the disposal concept has subsequently changed to a dry host rock

Position(s) in the matrix tables*:* The Osamu Utsumi Mine study is relevant to the near-/far-field interface saturated zone (initiation, propagation and retardation potential of redox fronts; high temperature gradients) and the far-field (mobilisation and transport of radionuclides under high temperature conditions) matrix tables. Common to both is the testing of geochemical equilibrium thermodynamic codes and databases

Limitations: Although originally crystalline in origin, hydrothermal alteration of the host rock has rendered it more compatible to a clay-based host rock. In this respect evolution of the redox fronts is relevant to disposal concepts based on: 1) bentonite backfill material, and/or 2) a clay-based host rock. Since there are differences in mineralogy, chemistry and physical properties (e.g. porosity), there are limitations to the degree of relevance.

Quantitative information*:* Most information which has resulted from this study has been semi-quantitative or qualitative and very useful in respect to 'confidence building' and scenario development with respect to redox front evolution under ambient conditions and their role in radionuclide mobilisation and retardation.

Uncertainties: On a scale of low-medium-high, the uncertainties are assessed as being medium to high because of the difficulties of establishing boundary conditions to the processes studied.

Time-scale: The time-scale addressed by the study is geological, both Quaternary (<2 Ma) and beyond (>2Ma).

PA/safety case applications: Examples of their use in published PA include:

- TVO — Use of colloidal and microbial information
- Kristallin-1 — Bounding conditions on redox front development to qualitatively support redox retardation of radionuclides

With respect to PA-related modelling:

- SKB-91 — Support for redox model models. Radionuclide solubility model testing (BPM)
- AECL EIS — Radionuclide solubility model testing (BPM)
- Kristallin-1 — Radionuclide solubility model testing (BPM) Testing models for redox front development
- SR-97 — Testing models of redox front propagation

Communication applications*:* Good illustrative material. Previous uses of the analogue in communication and dialogue material for different audiences include official SKB and Nagra brochures, the SKB mobile exhibition and its inclusion in the CEC-coordinated natural analogue video ('Traces of the Future').

References:

Chapman, N.A., McKinley, I.G., Penna Franca, E., Shea, M.E. and Smellie, J.A.T., 1992. The Poços de Caldas Project: An introduction and summary of its implications for radioactive waste disposal. J. Geochem. Explor., 45, 1-24. *In:* N.A. Chapman, I.G. McKinley, M.E. Shea and J.A.T. Smellie (Eds.), The Poços de Caldas Project: Natural analogues of processes in a radioactive waste repository. Special Issue of J. Geochem. Explor., 45, pp 603.

Nagra, 1993. Poços de Caldas: Nature's experiments. Nagra Bulletin (1/93).

Added value comments: The Osamu Utsumi Mine study profited greatly from a concerted international effort representing different types of disposal ideas and concepts and scientific experience. Of prime importance was the derivation of a good conceptualisation of the site based on a rigorous geological, hydrogeological and hydrogeochemical characterisation and the production of high quality data. Furthermore, it was the first analogue project that fully integrated, in the field and laboratory, geoscientific personnel from different disciplines with end-users involved in repository performance and safety assessments.

Potential follow-up work: Any further work in the field is effectively ruled out in the long term as the mine is due to be decommissioned in the near future. Much of the project rock sampling from outcrop and drillcore, however, is archived officially at the University of Bern and therefore easily accessible for study. Of importance would be a reappraisal of the large body of existing data which includes high concentrations of radionuclides and other relevant trace elements (REEs etc.). These data could be used to test a new generation of geochemical codes looking at speciation, solubility control, precipitation/co-precipitation, surface complexation, *in-situ* Kds and organic complexation etc. Continued redox front studies are no longer of interest as radiolysis reactions can be buffered effectively by present near-field engineered barrier designs.

Keywords: Uranium, redox fronts, hydrothermal, model testing, microbes.

Reviewers and dates: John Smellie (June, 2004).