Tono Mine (Japan)

Description: The Tono uranium ore deposit in Gifu Prefecture (e.g. Yamakawa, 1991; Yusa et al., 1993; Yoshida, 1994; Yoshida et al., 2000) is the largest known in Japan and is estimated to have been formed approximately 10 Ma ago (Ochiai et al., 1989; Kobayashi, 1989). The uranium deposits are distributed in the lowest part of the Mizunami Formation and are considered to have formed when uranium in the Toki granite was leached by oxidizing groundwaters, transported to the overlying sediments and then deposited and concentrated in a locally reducing environment (Katayama et al., 1974) - see Figure 1.

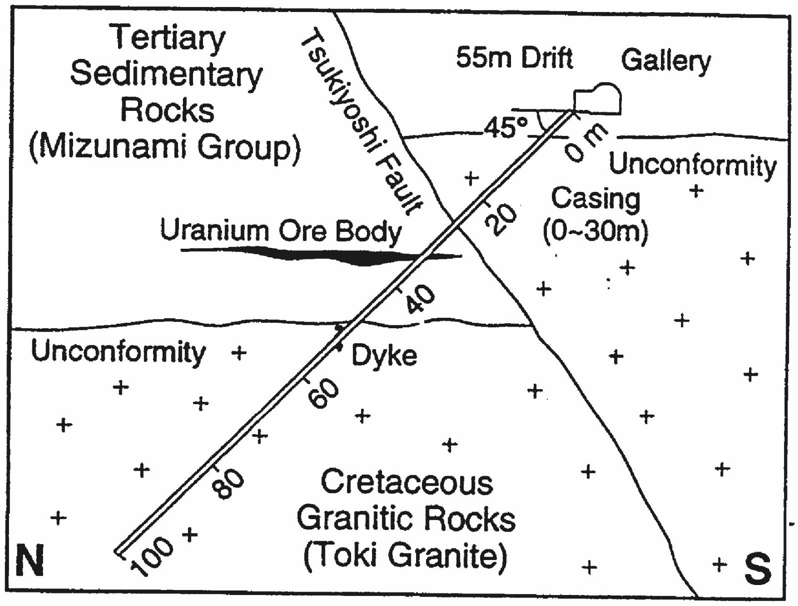

Figure 1: Cross-section through the Tsukiyoshi ore body at Tono showing its location in respect of the Tsukiyoshi Fault. Diagram courtesy of JNC (from Miller et al., 2000).

Between 5 and 15 Ma ago, the area was uplifted and the upper part of the Mizunami Formation experienced denudation (Itoigawa, 1980). The repeated activity of the Tsukiyoshi Fault, formed after the uranium deposit, shifted the Mizunami Formation approximately 30 m in a vertical direction (see Figure 1). This fault also intersected and displaced the uranium ore body, but no evidence for uranium being transported significantly along the fault has been found (Shinjo et al., 1997).

Following denudation up to approximately 5 million years ago, the area subsided and rivers and lakes formed. The sand and clay deposited during this period (the Seto Formation) covered the Mizunami Formation (Itoigawa, 1974) and this sedimentation continued until approximately 100,000 to 700,000 years ago, when denudation recommenced. The Tono uranium ore deposit has remained intact since it was formed c.10 Ma ago, despite experiencing fault movement, uplift, subsidence, denudation, sedimentation and climatic and sea-level changes.

The ore bodies at Tono lie in palaeo-channels in the unconformity between the Cretaceous basement (the Toki Granite) and the overlying Miocene fluvio-lacustrine sedimentary unit, which is the lowest unit in a pile of Miocene and Pliocene marine and lacustrine sedimentary rocks. These sediments are generally around 200 m thick, although they can be up to about 370 m thick in places. The largest of the Tono uranium deposits is the Tsukiyoshi uranium ore body, which has been the focus of most of the natural analogue studies in the area. This ore body has not been commercially exploited and only one gallery at a depth of 130 m below the ground surface has been constructed so the ore body can be examined in a relatively undisturbed state. The Tsukiyoshi ore body is approximately 3.4 km long, between 300 to 700 m wide and is a few metres thick. This ore body was split into two sections between 10 and 5 Ma ago by the Tsukiyoshi Fault, which does not cut the uppermost rocks of the Seto Group.

The Toki Granite rocks contain about 6 ppm uranium and are considered to be the source of the Tono uranium mineralization. The sediments at the unconformity (the Toki Lignite-Bearing Formation) contain significant quantities of carbonaceous material and pyrite in a highly reducing environment. The uranium mineralization itself occurs in conglomerate, sandstone and the lignite-bearing formations. The primary, un-oxidized uranium ore in the Tono deposit appears grey or black and comprises accumulations of coffinite and pitchblende, closely associated with pyrite, altered biotite or coaly plant materials in or around the porosity of the sediments. The secondary, oxidised uranium mineralization appears yellowish and is comprised of a variety of uranium-bearing minerals including autunite, zippeite and uranocircite, and is accompanied by montmorillonite, limonite and other minerals in the oxidised zones.

The ore body is thought to have formed when oxidising groundwaters leached the uranium from the Toki Granite and transported it upwards into the lignite-bearing rocks, where the uranium was precipitated or adsorbed, or both, under the more reducing conditions that prevailed there. No substantial remobilisation of the uranium has occurred since this initial deposition c.10 Ma ago.

The hydraulic conductivity of the sedimentary rocks hosting the uranium ore is low, between 10^{-8} and 10^{-11} cm/s. The groundwater in the region of the uranium ore is of the Na^{+}-HCO_3^{-} type, is strongly reducing and weakly alkaline (pH 8.7 to 9.5). The uranium content of the groundwater is generally low, about 0.05 to 0.2 ppb, although geochemical calculations suggest that the groundwater is saturated with respect to uraninite and coffinite. These thermodynamic solubility and speciation calculations also show that the redox environment is controlled by siderite or pyrite. Hydrogen and oxygen stable isotope studies show that the deep groundwater has a meteoric origin and preliminary ^{14}C measurements suggest an age between a few thousand and ten thousand years old.

Other investigations at Tono have focussed on uranium mobilisation at the mineral grain scale in the ore and surrounding rocks. To this end, hundreds of samples collected from the mine and from boreholes were analysed in uranium-series disequilibrium studies. Results indicate that reducing conditions have been maintained for at least the last million years, and the uranium mobilisation has been limited to very slow diffusion in the rock matrix and in micro-fractures in mineral grains.

The natural analogue studies at Tono are important because they demonstrate that the uranium ore body has remained largely unaffected by the continued tectonic activity in the area over the last 10 Ma since its formation. Although one fault cuts through the ore body, and other large faults lie close by, there is no evidence that significant uranium transport has occurred along these faults. This is a particularly important finding because, in most repository concepts in fractured hard rock, large faults are considered to be the only natural transport route for radionuclides to return to the surface. The fact that significant fracture-based transport has not occurred at Tono suggests that, provided the chemical environment in a repository near-field remains stable and reducing, tectonic activity will not necessarily cause uranium release from the wasteform.

The Tono natural analogue studies have been reported in a number of conference proceedings and journal papers e.g. Seo and Yoshida (1993) and other papers cited in the TAP Bibliography (2001).

Relevance: The Tono study is relevant to the deep disposal of spent fuel, and demonstrates minimal long-term impacts (physical and chemical) from natural disruptive events, particularly tectonic activity involving uplift and faulting.

The uranium minerals of the ore body are broadly analogous to a spent fuel wasteform.

Position(s) in the matrix tables: The Tono natural analogue study belongs to the Spent fuel/Barrier Containment-Physical Integrity box of the Near-field matrix table. It can also belong to the Spent fuel/Barrier Containment-Chemical Integrity box of the same matrix table.

Limitations: The Tono analogue study suffers from the general limitation that applies to all natural uranium ore body studies i.e. the primary mineral assemblage does not mimic exactly the solid phase compositions to be found in spent fuel rods.

The Tono study is a useful analogue for a deep repository provided the repository is expected to be located in a chemically reducing environment that would persist in the rocks surrounding the cavern for millions of years.

Quantitative information: Many geochemical data are available on the ore body and surrounding rocks. The natural groundwater U-238 concentration in the Toki Granite rock is ~$5x10^{-1}$ Bq m^{-3}, and in the overlying sedimentary rock ~$5x10^{-2}$ Bq m^{-3}. The concentration of groundwater colloids is low in the Tono mine, with 1 to 1.5 mg l^{-1} (size range 1 µm to 20 nm). These colloids consist mainly of sulphur-rich particles and silicate and carbonate minerals, but none is apparently associated with uranium, thorium or rare earth elements.

Uncertainties: On a scale of low-medium-high, the uncertainties in both the qualitative and quantitative information from the study are considered to be low. High quality data continue to be derived from ongoing analogue studies at the Tono Geoscience Centre.

Time-scale: The time-scales covered by the Tono analogue are geological (>2Ma & <2Ma), involving the last 10 Ma.

PA/safety case applications: The study has been applied in the H12 Project in Japan (JNC, 2000), in a generic performance assessment of a deep geological repository for high-level radioactive waste.

Communication applications: It would be interesting to know how the findings from the Tono analogue studies have been used in dialogue with the public in Japan.

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Added value comments: The Tono analogue is a good illustration in support of the concept of long-term geological disposal of high-level radioactive waste. This aspect could be better exploited by radioactive waste managers in their dialogue with the general public.

Potential follow-up work: The Tono Geoscience Centre is continuing research at the Tono site.

Keywords: uranium, spent fuel, containment, uplift, faulting, colloids

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