Isle of Skye (Scotland)

Description: The Isle of Skye is the largest of the Inner Herbidean islands, lying just off the north-west coast of Scotland (Figure 1). It has a complex and varied geology, and the exposed rocks range from the Precambrian in the south of the island, through the Mesozoic (mainly Jurassic sediments of interest to this study) in the centre and the east of the island, to Tertiary igneous rocks mainly in the centre of the island. On Skye, the total thickness of Lower, Middle and Upper Jurassic strata exceeds 500 m and are comprised mainly from shales with some limestones and lesser amounts of sandstones (Pellegrini et al., 1999). The smectite rich Jurassic shales are cut by a Tertiary igneous (basaltic) intrusion of 2-3 m width, with an estimated intrusion temperature of about 1200 to 1250°C. The hydrothermal fluids driven by the emplacement of the igneous intrusion, reached the base of the zone of alteration of smectite to illite (Woods et al., 2000).

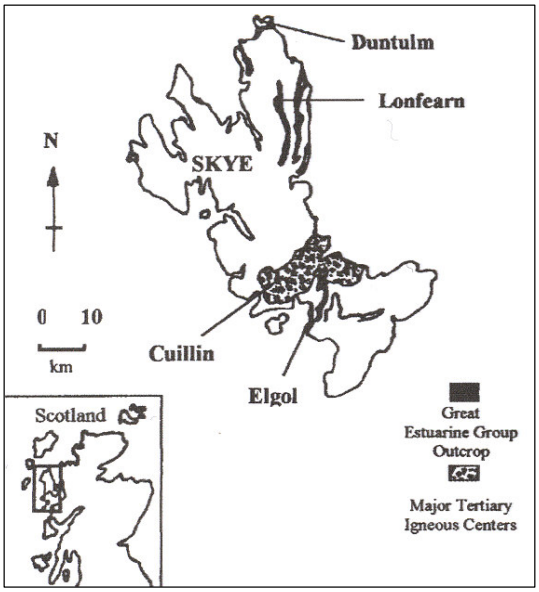

Figure 1. Location of Isle of Skye (Woods et al., 2000)

The non-altered or 'undisturbed' mudstone bed is typically composed of a silty mudstone with a weakly aligned fabric. Silt-sized grains of quartz, albite and K-feldspar together with shell fragments and abundant pyrite are held in a clay matrix. The presence of calcite, dolomite (and/or ankerite), siderite, gypsum and hematite were also noted (Pellegrini et al., 1999).

In general, the host mudstone mineralogy does not appear to be significantly altered beyond 6 m (2 dykes widths) from the contact with the intrusion. At distances less than this however, a variety of mineralogical transformations has taken place. The new forming of di- and tri-octahedral smectite close to the intrusion (Bouchet et al., 1999), the original smectite north of the dyke (Figures 2, 3 and 4) and an illite/smectite composition south of the dyke (Woods et al., 2000) are the results of several analyses (Woods et al., 2000, Pelligrini et al., 1999). This formation of new minerals may be evoked by retrograde or 'back' reactions during the temperature decrease following the major thermal event, which means that there is no chemical mixing between the intrusion and the original mudstone (Woods et al., 2000).

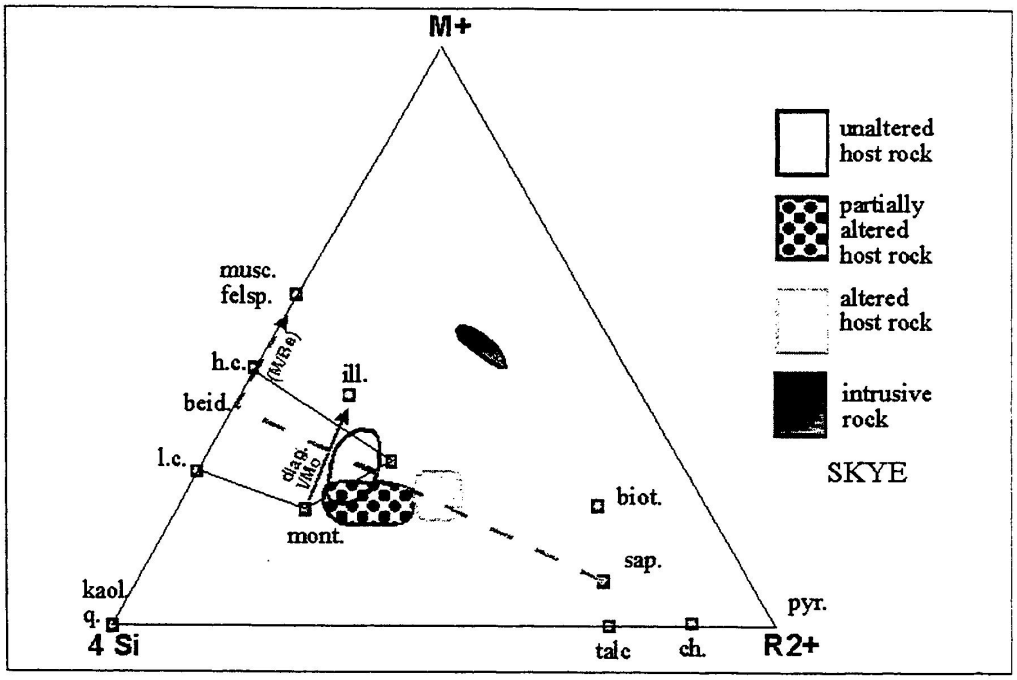

Figure 2. Chemical composition of the studied samples plotted in the M^{+}-4Si-R^{2+} system (iron as Fe^{2+}; CaO of calcite substracted). Abbreviations: q: quartz; kaol: kaolinite; beid: beidellite; mont: montmorrillonite; h.c.: high charge; l.c.: low charge; ill: illite; musc: muscovite; felsp: feldspar; biot: biotite; sap: saponite; ch:chlorite; pyr:pyrite (Pellegrini et al., 1999).

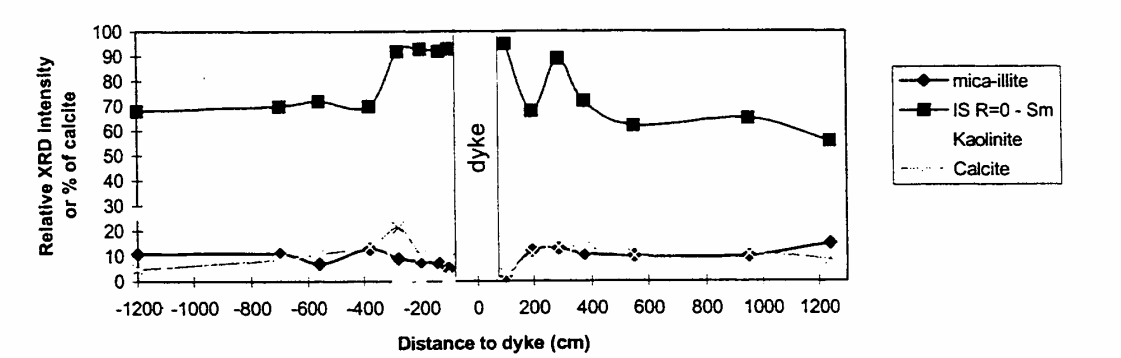

Figure 3. Evolution of XRD relative peak intensity of the major clay minerals and of measured % calcite (Pellegrini et al., 1999)

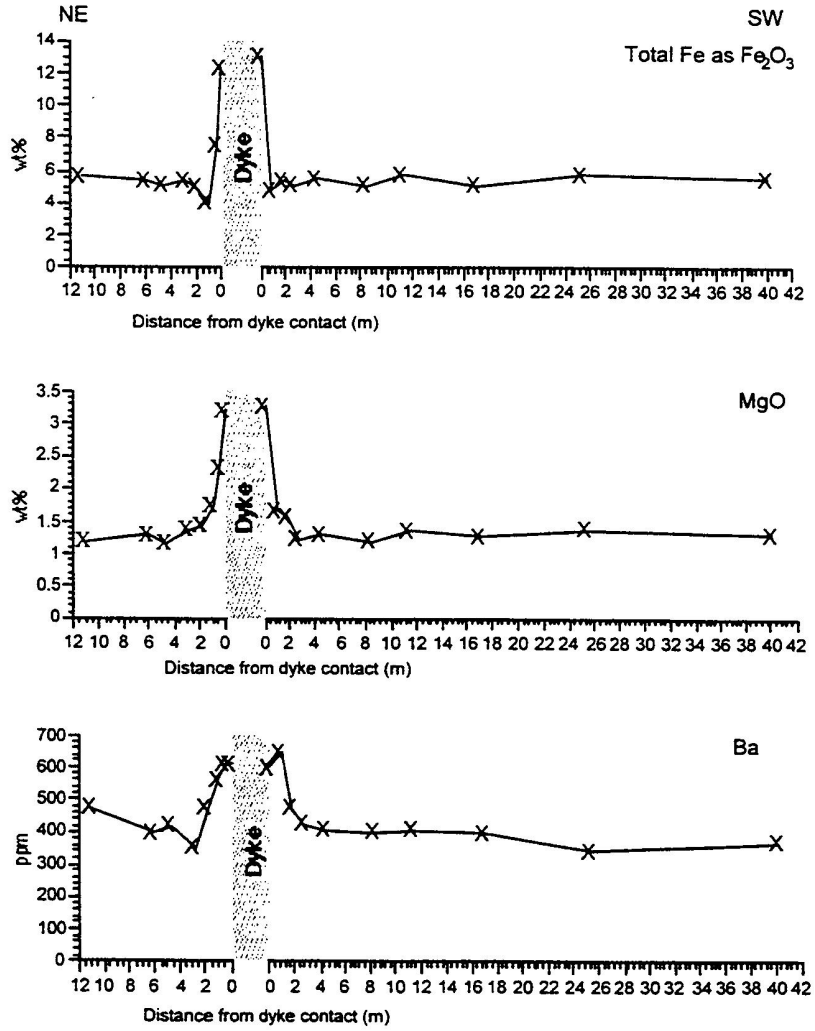

Figure 4. Evolution of CEC (meq/100g) and of % Oxides (Pellegrini et al., 1999)

Another remarkable result according to Woods et al. (2000) is the demagnetization of the clay that can be used for dating and as an indication of the smectite to illite transformation. A weak magnetization with random directions and a low magnetic susceptibility in the north is in contrast to the higher magnetic intensity and susceptibility and to three-component magnetization, found in the south. Because the directions for these components are similar to those from Tertiary igneous rocks on Skye, which are interpreted to contain a primary magnetization (Dagley et al., 1990 in Woods et al., 2000), the demagnetization and with it the mineral association in the clay is interpreted to be Tertiary in age. The IRM (isothermal remnant magnetization) acquisition and thermal decay curves suggest also that the magnetization in the south resides in two minerals: for the high temperature component magnetite, whereas the low temperature component may reside in pyrrhotite. This research revealed that the sediments in south Skye already contained a two-component ancient magnetization. The directions for the components are however the same as for Tertiary igneous rocks on Skye and so, the newly formed changes are, therefore, secondary magnetizations.

Maximum unblocking temperatures of 550–580°C are found for the north-directed component. Based on the curves of Pullaiah et al. (1975, in Wood et al., 2000), this component can not be a thermoviscous remnant magnetization (TVRM) and is, therefore, interpreted to be a CRM that resides in magnetite. The south-directed component with a lower unblocking temperature (340–425°C) resides

in pyrrhotite and could be a TVRM or a thermochemical remanent magnetization (TCRM) (Woods et al, 2000). The general thermal history of the mudstone, based upon a background paleotemperature of about 50°C gives following results: >300°C within ~0.25 -~0.5m of the dyke; >200°C within 1-3m of the dyke, and >100°C within 6m of the dyke (Bouchet et al, 1999).

For the fracture studies, there appeared to be a subtle change in mudstone appearance over a distance of about 30 m from the contact with the igneous rock. Nearer to the contact, the mudstone breaks into small (approximately 5-10 mm across) ragged 'flakes' along small polygonal fractures. These flakes appear to get larger and fewer away from the contact until they merge into 'country-rock' texture and fabric of the mudstone (Rochelle et al., 1997 in Pelligrini, 1999).

Relevance: The smectite bearing nature of the Skye mudstones is analogous to some host-rocks, and buffer and backfill materials being considered for disposal of heat-emitting radioactive-waste, and might initially be expected to react in a similar way as explained. The newly formed smectites or illites in the vicinity of a repository for high level waste, would contribute in most of the cases to reinforcing the adsorption capacity of clay for radionuclides, by causing an important neoformation of minerals. The temperature is in that way important that it, together with the chemical circumstances defines which transitions disappear.

Position(s) in the matrix tables: Near-field matrix properties of buffer materials.

Limitations: The first limitation is the absence of radionuclides, so this analogue does not allow verifying in situ the hypothesis regarding the retention capacity of heated clay for these elements. Secondly, the thermal effect in the south caused by the intrusion is for some elements much higher than the rise expected in the vicinity of the waste (about 100°C).

***Quantitative information*:** For sites in north Skye, the mean magnetic susceptibility is $4.00 * 10^{-8}$ Am^2 /kg and the mean natural remnant magnetic intensity is $3.14 * 10^{-7}$A m^2 /kg. Sites in south Skye have a mean susceptibility of $1.70 * 10^{-7}$ Am^2 /kg and a mean natural remnant magnetic intensity of $2.32\ 10^{-6}$ Am^2 /kg.

***Uncertainties*:** The reactions of the limestone on the thermal heating and the radionuclides.

***Time-scale*:** geological (max. 65 MY, min. 1,5MY; exact date is not found)

***PA/ safety case applications*:** None identified.

***Communications applications*:** None identified.

References:

Bouchet A, Boisson J-Y, Kemp S.J, Parneix J-C, Pellegrini R and Rochelle C. 1999. Mineralogical and chemical changes due to volcanic intrusion into clay formations, pp. 111-123; in Von Maravic H and Alexander WR (eds.). Nuclear science and technology Eighth EC Analogue Working Group Meeting. 2002. Euratom, p. 392.

Pellegrini R, Horseman S, Kemp S, Rochelle C, Boisson J-Y, Lombardi S, Bouchet A, Parneix J-C. 1999. Natural analogues of the thermo-hydro-chemical and thermo-hydro-mechanical response. European Commission (EUR 19114), pp. 47-60.

Woods SD, Elmore RD and Engel MH. 2000. The occurrence of pervasive chemical remnant magnetizations in sedimentary basins: implications for dating burial diagenetic events. Journal of Geochemical Exploration, 69-70, pp. 381-385

***Added value comments*:** None to add.

***Potential follow-up work*:** Research could be carried out on the effects of island's igneous intrusions on the surrounding limestone strata (reactions, cracks, permeability, …)

***Keywords*:** demagnetization, igneous intrusion (basaltic), illite, Scotland, smectite

***Reviewers and dates*:** Laurent Wouters & Astrid Verheyen, ONDRAF/NIRAS (April 2004)