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Simulation of co-seismic secondary fracture displacements for different earthquake rupture scenarios at the proposed nuclear waste repository site in Forsmark

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1. Introduction

The concept for storing spent nuclear fuel favoured by The Swedish Nuclear Fuel and Waste Management Co (SKB) is the KBS-3 system [1], in which the fuel will be encapsulated in canisters that are deposited at about 500 m depth in crystalline rock and surrounded by a high-density bentonite clay barrier. SKB has applied to the Swedish government for a license to construct a KBS-3 repository at Forsmark in southeastern Sweden, a low seismicity region where the largest historic earthquake was a magnitude 5.4 event in 1904 (Fig. 1). Since the repository safety assessment involves very long time perspectives, it has to account not only for the potential effects of low probability large earthquakes occurring under present-day stress conditions but also for effects of earthquakes triggered by stress and pore pressure variations caused by future glaciations [1,2]. For the latest, Weichselian, glaciation, the endglacial phase, i.e., the time of ice retreat, is commonly recognised as a period of increased seismicity in the Baltic Shield [3,4]. For the KBS-3 repository, the concern is that seismic events on pre-existing faults close to or within the repository footprint may induce secondary fracture shear movements with the potential to damage canisters (Fig. 2). In the safety assessment submitted along with the application to construct the repository [1], SKB applied a canister failure criterion stating that a canister sheared more than 50 mm is considered failed.

Fälth et al. [5] presented a method to calculate the amount of secondary shear displacements on so-called target fractures induced by the combined dynamic and static stress effects of an earthquake occurring on a nearby deformation zone, the primary fault. They made a preliminary application of the method (denoted FMF in the following) to the Forsmark repository site where they selected the gently dipping shallow ZFMA2 deformation zone [6] to be the primary fault (Fig. 1c), failing in reverse faulting under endglacial stress conditions [7]. None of the glacially accumulated strain energy was released prior to rupture initiation. With the hypocentre located close to the repository horizon and with a rupture velocity of 70% of the elastic shear wave velocity, the entire 12 km^2 area of the fault ruptured in one single reverse faulting event with nearly complete stress drop. The moment magnitude amounted to M_w 5.6, while a typical crustal earthquake on the same rupture area would be smaller, about M_w 5.3 [8]. The maximum fault slip velocity was on par with values recorded for much larger real earthquakes (e.g. [9]). Out of 1584 target fracture displacement results, obtained for 22 fracture orientations on 150 m radius perfectly planar fractures, located at 200 m, 400 m and 600 m distance from the primary fault, only four exceeded the 50 mm canister failure criterion. These four fractures were located at 200 m distance in the hanging wall. In the footwall, where the repository will be constructed, no displacements exceeded 30 mm.

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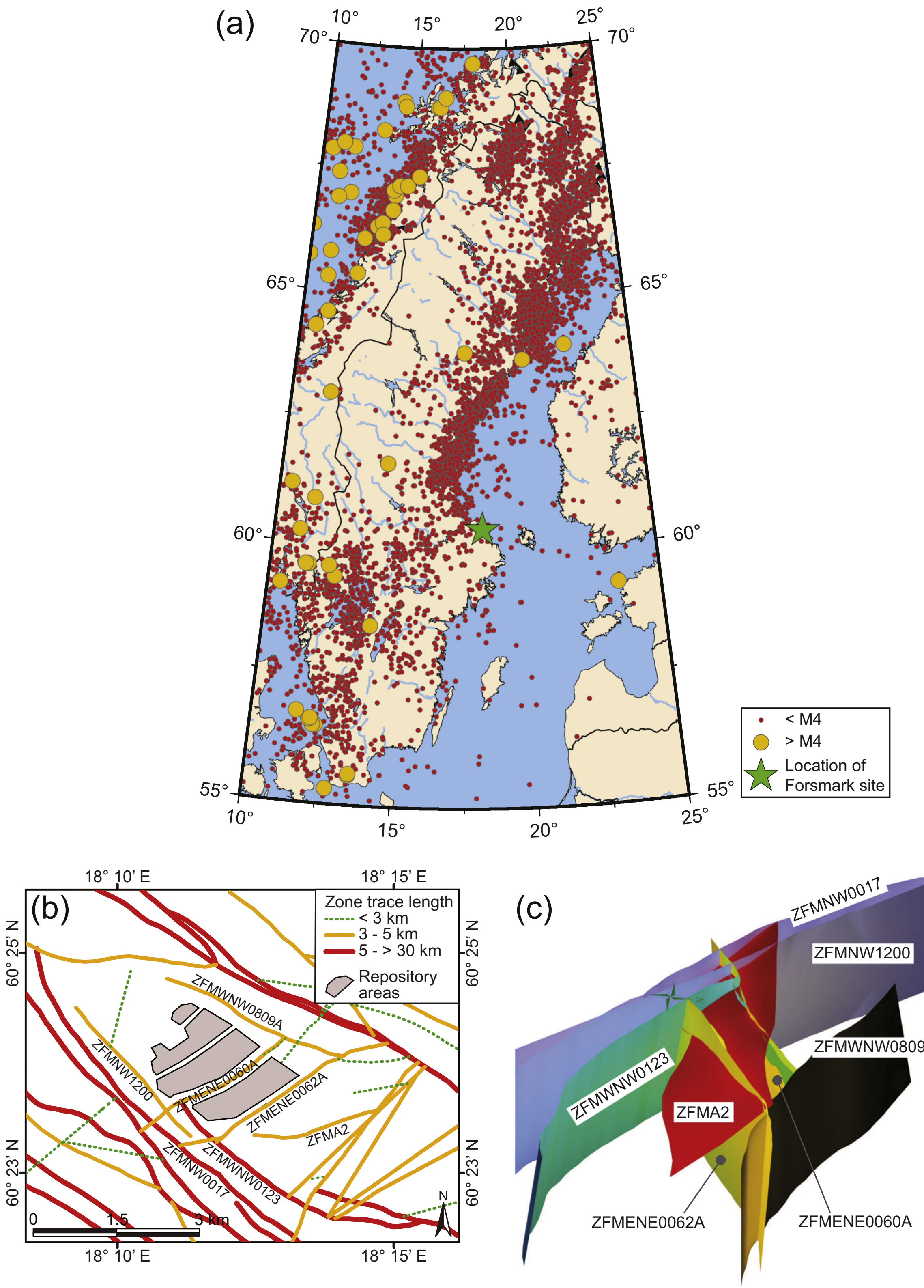

Fig. 1. (a) Present-day seismicity of Scandinavia between 1904 and 2004 [36,37], (b) deformation zone map at the projected repository depth 470 m in Forsmark [38], and (c) 3D view of zones surrounding the repository volume viewed towards west [18,35].

Due to the strong earthquake source and the planar target fracture geometry, Fälth et al. [5] considered these results to be over-estimates of corresponding effects of a real earthquake occurring on a Forsmark deformation zone.

A number of potentially important issues were not addressed in FMF. The model did not include any faults other than the primary fault ZFMA2. Other large deformation zones identified at the Forsmark site are all steeply dipping (Fig. 1c), clamped by high normal stresses and thus have considerable stability margins (Fig. 3). However, they could affect processes such as the stress redistribution around the edges of the ZFMA2 earthquake zone.

The induced secondary displacements could potentially be