Collapse of the Methodology Applied in Sweden and Finland for the Deposition of High-level Nuclear Waste

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The nuclear industries in Sweden and Finland claim that high-level nuclear waste can be safely buried in the bedrock according to the KBS-3 method for at least 100,000 years (SKB in Sweden) or 1 million years (Posiva in Finland). In view of paleoseismological observational facts and modern geodynamic views on the processes operating in the bedrock over the required time period, it is concluded that the KBS-3 method is, in fact, facing a collapse. Therefore, it would be a serious mistake if France adopted this technology. An alternative solution must be found. A Dry Rock Deposit (DRD) is proposed.

1. The Swedish Paleoseismic Database

As a function of the very high rates of glacial isostatic uplift at the time of deglaciation about10,000 years ago, the seismic activity in Sweden was exceptionally high (e.g. Mörner, 1985, 1991, 2003, 2011, 2013a; Mörner et al., 2000). The "seismic landscape" of Fennoscandia at the time of deglaciation is characterized by frequent high-magnitude paleoseismic events (Mörner, 2013a). Mörner (2011) recorded 7 high-magnitude events during 102 years from varve year 10,490 to 10,388 BP. Several events must have reached a magnitude of well above 8 (Mörner, 2003, 2011, 2013a). Active faults occur from northernmost to southernmost Sweden (see the map of "active tectonics and postglacial paleoseismics" in Mörner, 2004). In northernmost Fennoscandia, there are a number of very large and long fault scarps denoting high-magnitude events (or repeated movements).

Paleoseismology includes the study both primary structures (i.e. faults and fractures in direct association to the epicentre) and secondary effects from ground shaking (i.e. rock and sediment slides, sediment deformations, liquefaction, tsunami events, turbidites, magnetic grain rotation, etc.). A key factor is dating. The varve chronology in Sweden offers an exceptional means of dating seismic events to one single varve year, in a few cases even to the season of a year (Mörner, 2003, 2011, 2013b).

The maximum earthquake magnitude increases dramatically back in time, viz.: below 4.8 in seismology of the last century, >5.5 in historical records of the last 600 years, ~7 in paleoseismic records of the last 5000 years and well above 8 in multiple paleoseismic records of the last 11,000 years (Mörner, e.g. 2013a). This implies that a meaningful long-term hazard assessment can only achieve if the paleoseismic records of past earthquakes are included.

The Swedish Paleoseismic Catalogue is constantly updated (Mörner, 2003, 2004, 2005, 2011, 2012, 2013a). At present it includes 62 events (Mörner, 2013a, Appendix A). As a first, approximate way of assessing the seismic hazard of the next 100,000 years, this database may simply be multiplied by 10 (Mörner, 2013a) for all the 59 events recorded after the ice retreat, for all events within a radius of 250 km and for the events recorded in the direct vicinity of the repository proposed at Forsmark in Sweden and at Olkiluoto in Finland. The records within the radius of 250 km seem most relevant, as it fits well with the recommendation by IAEA (2010): "The size of the relevant region . . . is typically 300 km".

2. Methane Venting Tectonics

Methane venting tectonics is a novel process, first proposed by Björklund (1990; cf. Sjöberg, 1994) and later documented by Mörner (2003, 2011) and Mörner and Sjöberg (2011). The implication for hazard assessments is that it adds an additional consequence of earthquake events, which may significantly increase the bedrock fracturing in horizontal as well as vertical dimensions. The nuclear power industry claims (Bäckholm and Munier, 2002) that the bedrock fracturing is restricted to a few centimetres of displacement only 50–100 m from regional fracture zones (the "respect distance"). In reality, however, severe deformation on the order of many decimetres up to metres is observed at distances of 10 to 50 km from the epicentres (Mörner, 2003, 2011).

Methane occurs in nature in the form of gas or, in sediments and bedrock, in the form of ice (methane hydrate or clathrate). The volumetric relation between the ice and gas phases is 1:168, which implies a very large expansion when ice transforms into gas. The transition is phase-boundary controlled by temperature and pressure (as illustrated in Mörner, 2011, Fig. 12). During the postglacial period after an ice age, temperature increases and pressure decreases in response to land uplift. Both these processes affect the stability of an accumulation of methane ice in the bedrock. The ice/gas transition is instantaneous. Consequently, the chances are very high that this process will lead to an explosive venting of methane gas.

This is precisely what was documented in the field at studies in Sweden (Mörner, 2003, 2011); both in seepage of methane gas through the varved clay leaving spots of precipitated carbonate, and in a number of sites with violent bedrock deformation far away from the epicentre of the earthquake event that generated the methane ice/gas transformation and venting tectonics.

Even during the Late Holocene, we have two cases of violent methane venting tectonics. One occurred 2900 BP just north of Hudiksvall and set up a tsunami wave of 20 m height (Mörner, 2003, 2011, 2013b; Mörner and Dawson, 2011). The other site is located just south of Stockholm and seems to have occurred about 4000 years ago (Mörner and Sjöberg, 2011). In both cases huge blocks (of 1000 tons or more) were thrown up vertically, now resting at the top of cones of fractured bedrock blocks.

3. Location of Proposed Repositories

The proposed bedrock repositories in Finland and Sweden are both located in an area of very high seismic activity over the last 10,000 years (Fig. 1; cf. Mörner, 2003, 2013a). The KBS-3 method was designed to be "a final deposition" with no feasible way of retrieval in the future. In 2000, SKB made there own evaluation of the possibilities of retrieval and arrived at the conclusion that, if it would ever become technically possible, it would cost at least as much as the cost of deposition, and hence is not feasible Furthermore, such an operation would be extremely dangerous.

The observed bedrock faulting and fracturing in association with individual paleoseismic events exceed the "respect distance" used by SKB and Posiva in their repository designs by a factor of 1000.

The methane venting tectonics is a novel factor, which SKB and Posiva not yet have considered and addressed. It should be stressed that the bedrock around Olkiluoto is exceptionally full of methane gas (said to have caused severe problems already during the present phase of site investigations).

The paleoseismic records within an area of 250 km around the proposed repositories includes (Mörner, 2013a, Table 3): 4 events of M >8, 5 events of M 7-8, 19 events of M 6-7 and 7 events of M <6. If this seismic record (surely to be increased in the future) is simply multiplied by 10, it would give 40 events of M >8, 50 events of M 7-8, 190 events of M 6-7 and 70 events of M <6; i.e. a seismic activity, which surely is not acceptable, and surely cannot justify the claim of safe deposition for 100,000 years; rather the opposite.

Consequently, there are strong scientific reasons to claim that both the method and the locations cannot be considered to give "a safe deposition for 100,000 years in Sweden or 1 million years in Finland", as claimed by SKB and Posiva, respectively. It seems we are facing a direct collapse of the method proposed (Mörner, 2013c).

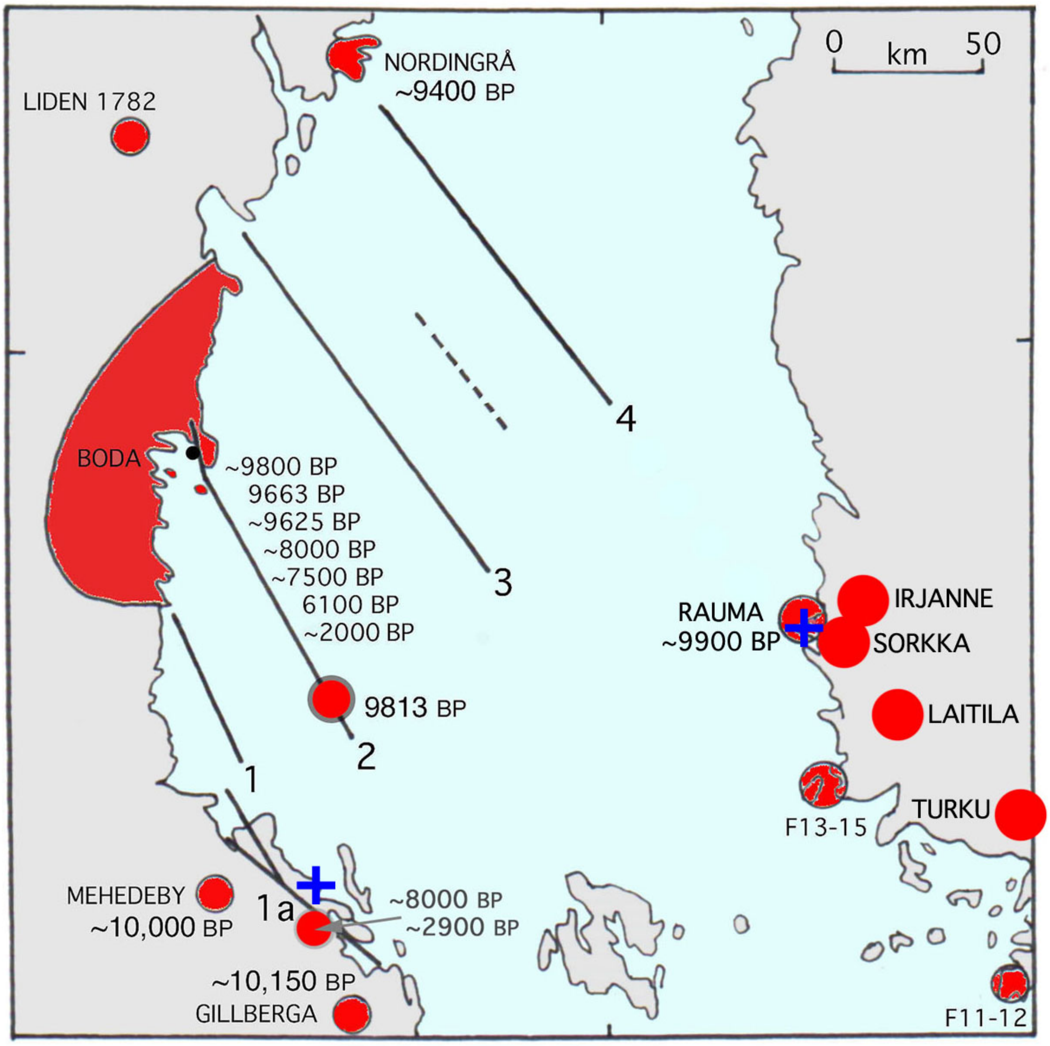

Figure 1. The Bothnian Sea region with all the paleoseismic events recorded in Sweden (Mörner, 2003, 2009, 2011, 2013) and Finland (Kuivamäki et al., 1998; Koltainen & Hutri, 2004; Mörner, 2010). Blue crosses mark the location of the proposed repositories of high-level nuclear waste at Forsmark (Sweden) and Olkiluoto (Finland).

4. Seismic Hazard Assessment

Storage of high-level nuclear waste in the bedrock has forced us to attempt to make seismic hazard assessments for a time period of at least 100,000 years. This almost impossible task is something that must be handled on the basis of an extensive paleoseismic database (Mörner, 2012, 2013a). The following conclusions (Mörner, 2013a) are drawn with respect to the seismic hazard of the area:

(1) The nuclear industries (SKB in Sweden and Posiva in Finland) make far too optimistic statements on the long-term seismicity, primarily based on current seismic data and in general ignoring available paleoseismic data.

(2) The seismic database covers far too short a time period to be applicable in longer-term hazard assessments. Furthermore the events are not representative of long-term frequency and magnitude.

(3) Loading modelling seems far too crude for serious hazard assessments. Furthermore, it is seriously contradicted in basic assumptions and in the fact that it fails to produce the observed events in deglacial and postglacial times

(4) A meaningful hazard assessments must be based on available paleoseismic data. This can be achieved in different ways (Mörner, 2013a, Table 3, Fig. 13). The results will differ, but the

main answer is clear, there will be far too many and far too strong events in the future to allow for a statement that a closed repository in the bedrock will stay intact over the required time period of at least 100,000 years. The opposite seems rather to be the case: not safe deposition but a collapse.

The solution to this "dead-end situation" is to abandon the KBS-3 concept and switch to a different methodology.

5. An Alternative Methodology

At present there is no safe way of rendering high-level nuclear waste harmless. New reactors, transmutation and thorium reactors are possible options for the future. To burry the waste in an inaccessible final deposit is irresponsible. Very much research is in progress with respect to future handling of the waste. Therefore, it should neither be encapsulated nor buried, but kept accessible. This can be achieved in a Dry Rock Deposit according to the DRD-method (Mörner, 2001, 2013d; Cronhjort and Mörner, 2004).

If a problem cannot be solved today, there is only one intelligent thing to do: wait and keep the freedom of action (waiting for future technological innovations).

A DRD repository implies a deposition in the bedrock under dry conditions. A high-relief topography is chosen and a suitable volume of rock mass is surrounded by an artificial fracture zone, which will serve to drain the bedrock so that the inside rock volume becomes dry. The deposition occurs in tunnels or rooms within the dry bedrock volume. The roof above is ideally in the order of 100-300 m. The surrounding fracture zones act as an excellent protection against earthquake damage. In a DRD repository the waste remains accessible though well protected and locked-in. The waste remains controllable and repairable. It can be re-used if future technological innovations so allow. It can even be totally re-located.

A DRD repository can be constructed in several different ways (Mörner, 2013d): as a zero option, as a safe bedrock deposit up to the next Ice Age, and even as a "final repository" if a favourable location is chosen. It is also considerably cheaper to build than a KBS-3 repository (in the order of 1/3 to 1/4).

6. Conclusions

Seismic hazard analyses based on available observational facts (Mörner, 2013a) invalidate the KBS-3 method. Observed faulting and fracturing of the bedrock (Mörner, 2003, 2011, 2012) has a spatial distribution which exceeds "the respect distance" applied by SKB and Posiva by a factor of 1000, invalidating the close spacing of waste canisters applied at Forsmark and Olkiluoto with respect to regional fracture zones. Methane venting tectonics is another reality that invalidates final deposition in the bedrock according to the KBS-3 method. In view of these facts, the KBS-3 method has collapsed (Mörner, 2013c). In this situation, a feasible solution is deposition in a DRD repository (Mörner, 2013d).

References

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All additional references can be found in Mörner, 2013a, accessible at www.pattern-recogn-phys.net/1/75/2013/