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SEISMIC HAZARD ASSESSMENT ON A NUCLEAR WASTE TIME SCALE

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Abstract (Seismic hazard assessment on a nuclear waste time scale): *Nuclear waste storage in the bedrock or sedimentary deposits calls for safety assessments over a time period of 100,000 years or even more. This may be to drive our assessments "in absurdum". Still, we have to do what we can, and this calls for sophisticated studies in paleoseismicity covering the deglacial period or preferably a full glacial/interglacial cycle. We investigate the situation in Sweden and Finland where repositories are in preparation. During the deglacial phase with a very high rate of glacial isostatic uplift, this region was a high-seismic area in magnitudes (M>8) as well as in frequency (6 events within 102 years). If this paleoseismological data base is not included in the hazards assessment, it will become meaningless and even directly misleading.*

Key words*: Hazard assessments, nuclear waste storage, paleoseismology, Sweden*

INTRODUCTION

For a proper handling of the future safety of buildings and constructions, we normally have to rely on careful seismic hazard assessments. In most cases, however, our seismological records are confined to measurements over some decades up to a century. This may do for short-term assessments. The instrumental records are far too short when it concerns longer-term assessments. Then we have to turn to paleoseismology and archaeo-seismology as illustrated in Fig. 1.

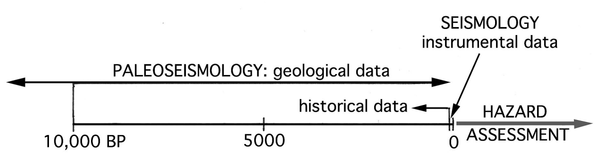

Fig. 1. A sound seismic hazard assessment must be founded on a combination of instrumental recording (seismology) and long-term recording by geological data (paleoseismology), archaeo-logical data (archaeosiesmology) and historical documentation (from Mörner, 2011).

When it concerns the construction of nuclear waste repositories in the bedrock or in sedimentary deposits, the safety assessment has to be extended over at least 100,000 years. In such a case, the seismological records becomes meaningless and, maybe, even misleading. The only means of obtaining any guidance for some sort of meaningful assessment is via careful and extensive investigations of available geological data; i.e. paleo-seismology. This is especially important in areas like Sweden and Finland where the seismic activity has changed considerably over the last 12,000 years as a function of the change from deglacial to postglacial environment; at the time of deglaciation and high rates of glacial isostatic uplift, Fenoscandia was an area of very high seismic activity in magnitudes as well as in frequen-cies (Mörner, 2003, 2011), whilst it today is an area an area of moderate to low seismic activity.

To extend a seismic hazard assessment over such an immense time period as 100,000 years may, in fact, be to carry the predictions "in absurdum" (Mörner, 2001). Still this is what is now required both in Sweden in Finland where underground repositories for high-level nuclear waste are under final assessment in Sweden and partly already under construction in Finland. In both cases, the seismic hazard assessments are quite badly performed by the responsible firms (SKB and Posiva).

In Sweden, it is claimed that the maximum seismic event in 100,000 years is one M 6 event, despite the fact that 5 events are recorded in direct vicinity of the repository planned and 21 additional events are recorded with a radius of 150 km (Mörner, 2003, 2011). Their own study (Lagerbäck et al., 2005) includes extensive trenching (recording multiple deformational structures) but with a very weak (not to say incompetent) interpretation. This provides us with a concrete example of the necessity of focusing on paleoseismological data and to do this with a modern view of its recent achievements.

In Finland, the situation is even worse. Very little was done with respect to meaningful seismic hazard assess-ment. Important paleoseismic data (e.g. Koltilainen & Hutri, 2004) were ignored. In the close vicinity of the repository site, I was later able to document multiple paleoseismic events (Mörner, 2010).

In this paper I will focus on the paleoseismic records in Swedish with respect to dating, recurrence, frequency, magnitude and multiple expression in primary and secondary effects. The implication for a repository in the bedrock over a ten times longer period is assessed.

PALEOSEISMICITY OF SWEDEN

The paleoseismicity in Sweden has been discussed in numerous papers (where the more recent ones are: Mörner et al., 2000; Tröften 2000; Mörner 2001, 2003, 2004, 2005, 2007, 2008, 2009, 2011; Mörner & Sun, 2008; Mörner & Dawson, 2010; Mörner & Sjöberg, 2011). In total, 61 events have been recorded in Sweden up to 2012 (Fig. 2); 3 from the pre-LGM interstadial, 46 from deglacial to Mid Holocene time when glacial isostatic uplift was still strong, and 12 from the last 5000 years, where the uplift conditions were more or less the same as today.

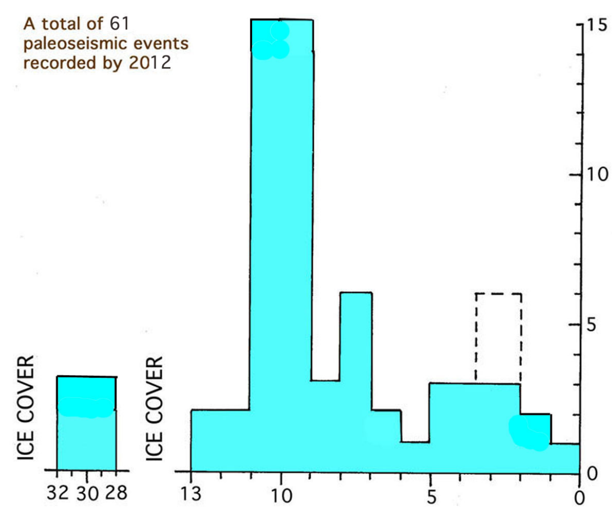

Fig. 2. Histogram of 61 paleoseismic events recorded and dated for every 1000 years over the past 13,000 years.

Fauls

The distribution of active faults and related secondary features in Sweden has been discussed elsewhere (Mörner, 2004). The Pärve and Lansjärv faults in northernmost Sweden are, indeed, spectacular features (Lagerbäck, 1990). The Falkberget Fault at Hudiksvall is impressive, too (Mörner, 2003). The Mälardalen area is traversed by an old E–W-trending fault, reactivated at in deglacial time with repeated events at high frequency and magnitude (Mörner, 2003, 2011, Fig. 10). The Kattegatt Sea is traversed by an active NW–SE-trending fault (Mörner, 2003, 2004).

Recurrence

Thanks to very sharp dating, it was possible to identify, date and establish the paleoseismic recurrence (Fig. 3).

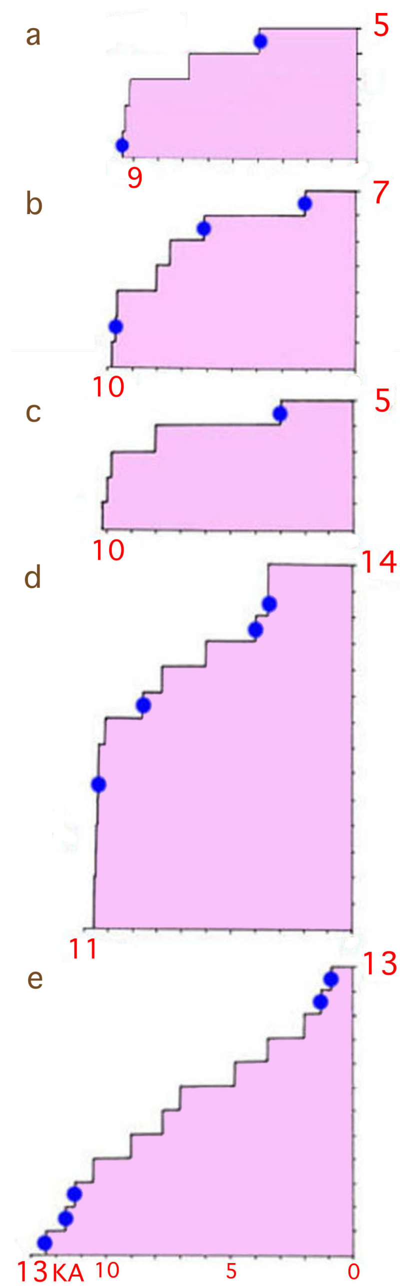

Fig. 3. Recurrence established at separate areas: (a) Umeå: 5 events in 9.5 KA, (b) Hudiksvall: 7 events in 10 KA, (c) northern Uppland (the Forsmark area): 5 events in 10.2 KA, (d) the Stockholm-Mälardalen area: 14 events in 10.6 KA, and (e) the West Coast area: 13 events in 13 KA. Blue dots mark tsunami events. A very high frequency of deglacial events was recorded in the Stockholm area (d): 6 events in 102 years. See Mörner (2003, 2009, 2011).

A high-sesmic region

The Bothnian Sea region with the proposed repositories for high-level nuclear waste in Sweden and Finland must be regarded as a high-seismic region in deglacial time as evident from the paleoseismic data recorded (Fig. 4).

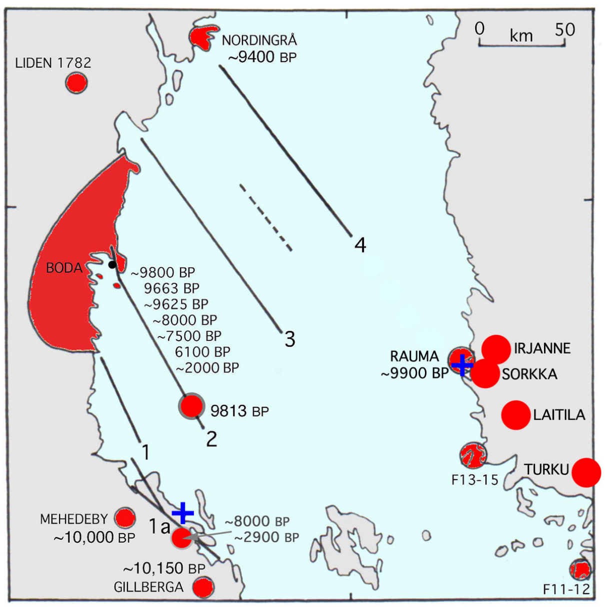

Fig. 4. The Bothnian Sea region with all the paleoseismic events recorded in Sweden (areas b-c in Fig. 3; Mörner, 2003, 2009) and Finland (Kuivamäki et al., 1998; Koltainen & Hutri, 2004; Mörner, 2010). Blue crosses mark the location of the proposed repositories of high-level nuclear waste at Forsmark (Sweden) and Olkiluoto (Finland).

The mere location of the repositories in this high-seismic region seems badly chosen, neglecting proper consideration of our science of paleoseismology. In view of all the observational facts available, it seems "remarkable" (to say the least) that the nuclear power agencies, in their so-called safety analyses, claimes that the maximum earthquake in 100,000 years will be one M6 event.

This is precisely why we have to insist that paleoseismology must play a central role in their safety and hazard assessments.

Magnitude estimates

It is, of course, not easy estimate magnitudes and/or intensities of paleoseismic events (Mörner, 2003, 2011). We use a combination of different available information: fault criteria, spatial distribution of bedrock fracturing, spatial distribution of individual liquefaction events, material and character of liquefaction structures, number of phases of liquefaction at separate events, type and distribution of slides, heights of tsunami events, spatial distribution of turbidites and mode and distribution of magnetic grain re-orientation.

The multiple criteria of the 10,430 and 9663 vBP have been discussed separately (Mörner, 2011) and they must both represent events of M>8 (and intensity XII). The Pärve (~9000 vBP) and Landsjärv (~0150 vBP) Faults must also represent >8 magnitude events. An event dated 10,388 vBP (Mörner, 2008, 2011) exhibits violent large-scale liquefaction structures including the venting of coarse gravel. At the 2008 IGC excursion, X said *"this must be the largest liquefaction structures ever described"*. This merits the assignment of M>8. Similarly, the 6100 BP event represents venting of coarse gavel and a tsunami wave of at least 15 m suggesting M8->8.

The liquefaction structures representing the 10,430 and 9663 vBP events have a spatial distribution of 320x100 km and at least 80x40 km (probably 150x100 km), respectively. Furthermore, the 9663 vBP event contains 5 separate phases (Mörner, 2003, 2005).

In total 17 separate tsunami events have been identified (Mörner, 2003; Mörner & Dawson, 2010). Their time and height distribution is given in Fig. 5.

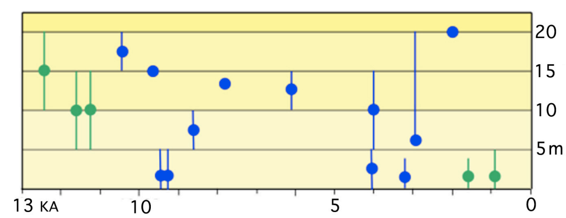

Fig. 5. Recorded heights of tsunami events in the Baltic (blue) and Kattegatt (green) coasts of Sweden.

The off-shore dynamics of the tsunami is given in Fig. 6 (from Mörner & Dawson, 2010).

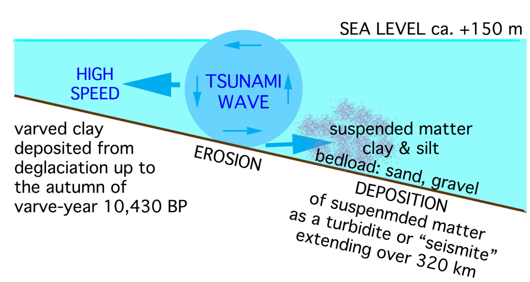

Fig. 6. Deformation, erosion and deposition in association with the 10,430 vBP event, generating a turbidite extending over an area of 200x320 km.

The varve 10,430 vBP turbidite is a marker varve of 10,430 BP identified in numerous sites with a spatial distribution of 320x200 km. It is always found at the same chronological level; varve 10,430 BP. In three sites, it has even been pinpointed at the autumn of this varve. The 9663 vBP event set up a similar marker bed with a turbidite extending over an area of 320x100 km.

The seismicity of Fennoscandia has changes considerably over the last 13,000 years (Fig. 1); 50% of the events occurred at the top rates of isostatic uplift (with M>8 and 6 events in 102 yarve years), 11 events are recorded over the last 5000 years (with M7, the youngest one at 900 BP), the historical events reached M5.4 in 1904 and the maximum present event M4.8 in 2008.

CONCLUSIONS

The safety analyses and seismic hazard assessments in association with the nuclear waste repositories at Forsmark in Sweden and at Olkiluoto in Finland are not adequately based on available paleoseismic data and geodynamical processes. Therefore, they should be regarded as insufficient and even misleading.

Though seismic hazard assessment over such immense time periods as 100,000 or more hardly is feasible and maybe even to drive predictions “in absurdum” (Mörner, 2001), we have – in view of our paleoseismological responsibility – to make the best estimates we can and to use all available facts and modern achievements.

In view of this, both the Forsmark area and the Olkiluoto area may over the next 100,000 years experience ~1000 M6 events, some ~100 M7 events and ~10 M8 events. In addition to this there is a threat of methane gas venting tectonics (Mörner, 2003, 2011).

In such an environment there can be no guarantees what so ever for a safe deposition of high-level nuclear waste in the bedrock; rather the opposite: it will not work.

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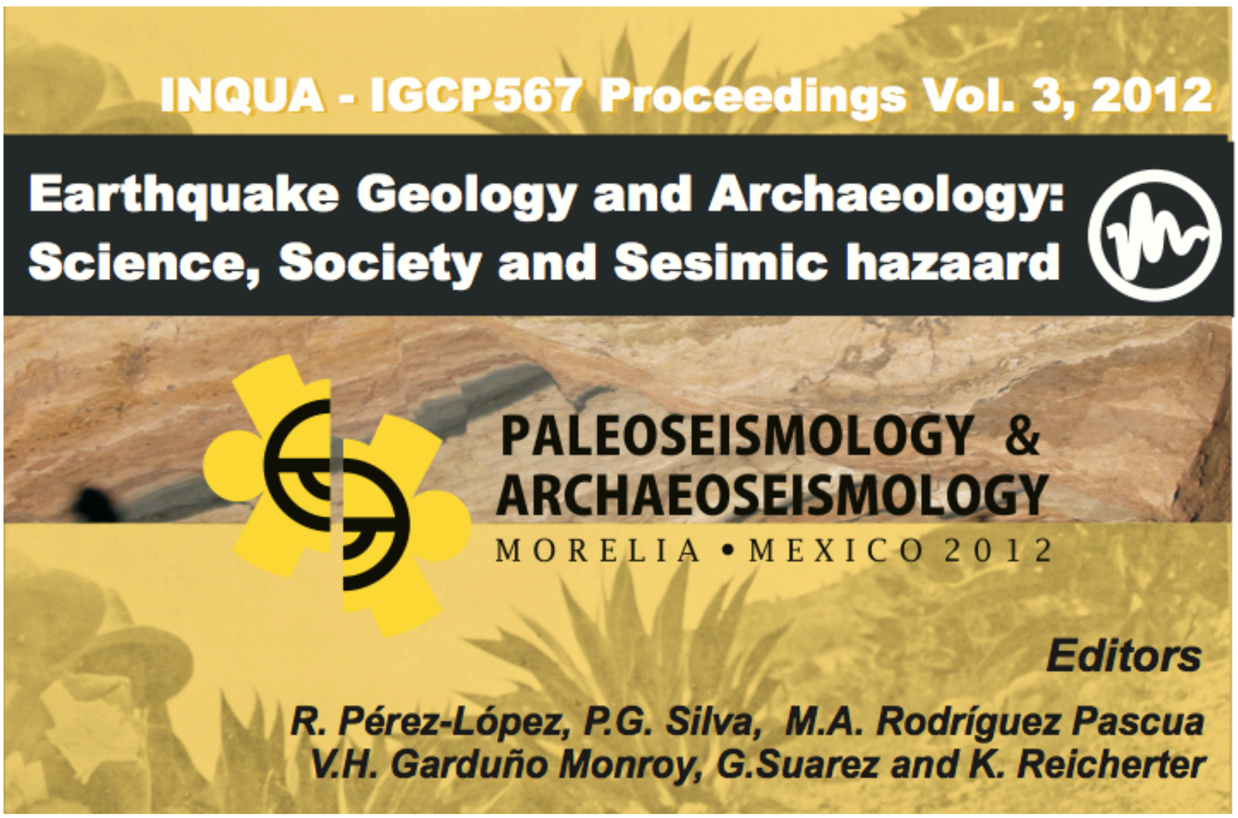

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