Seismotectonics and ground motion in Eastern Canada and North West Europe

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ABSTRACT: Intraplate seismicity operates according to a very long time scale, two to four orders of magnitude longer than the available historical record. Seismotectonic studies and methods from the formerly contiguous continental region of North West Europe can aid understanding of Eastern Canadian seismicity and seismic zonation: including geographical and temporal variations in seismicity, and the duration and configuration of contemporary seismotectonics. Detailed parametric studies of intraplate seismicity are required to select strong-motion data from more active regions more appropriate to the signature of seismic ground motion in Eastern Canada.

1 INTRODUCTION

From 400 until 100 million years ago, Eastern Canada and North West Europe were the same continent (laurasia) - the Iapetus suture zone, marking the site of the former Atlantic, passing from Newfoundland across to Ireland and Scotland. A series of rifting episodes, first between Greenland and Canada, and subsequently between Greenland and Europe fragmented Laurasia, and for the past 100 million years ago the regions have been on separate plates. Yet even while separated, these two 'passive-margin' regions have many parallels in their tectonic development, including proximity to a major Tertiary collision zone, evidence for dispersed deformation passing through the region, epeirogenic uplift around the North Atlantic, and finally the oscillatory formation and disappearance of thick continental ice-sheets.

Today both regions have some seismicity, generally of a low level, but capable of causing building damage and taking lives. For engineering planning, there is a clear need to know more about the likely location of future damaging earthquakes. To this end, an exchange of information may help to find answers to some of the most pressing problems of intraplate seismic hazard; in particular the return period of very large earthquakes.

2 TIMESCALES

The most important frame within which to view intraplate seismicity is that of the time scale. The period from one major fault movement until its repeat has come to be termed the 'seismic cycle'. Seismic cycles are unlikely to be regular or regionally consistent from one fault to another, but within a given section of equally deforming crust the return period of major earthquake generating fault movements, a notional 'regional seismic cycle', probably lies within one order of magnitude of time scale. This represents the duration of monitoring necessary to record a total picture of the pattern of coseismic crustal deformation. Estimates of the seismic cycle for Eastern Canada must be based on a) extrapolations from the association between seismic cycle time duration and seismicity obtained for more active regions, b) observations made directly from the geological record of intraplate seismic cycles.

The seismic cycle at plate boundaries is generally between 50 and 1000 years (Nishenko & McCann 1981). For areas of rapid continental deformation, such as China or Basin and Range, USA, it probably lies in a range of 1000 to 10,000 years (e.g. see Swan et al. 1980). For slowly deforming continental intraplate regions it is likely always to be more than 10,000 years, commonly longer than 100,000 years, and perhaps 1,000,000 years. Direct geological studies of the return period for major intraplate fault movements, as obtained in central USA, corroborate the latter figures. It is sobering to note that the largest event known from continental USA in the past two centuries was caused by a reverse displacement on the Reelfoot fault, Tennessee that has moved only 15m in the past fifty million years, perhaps equivalent to two or three such displacements (Sexton & Jones 1986).

Long duration seismic cycles undermine the principle in seismic hazard estimation of using past data. If the seismic cycle becomes longer than the duration of the current tectonic episode, then major fault movements may have had no modern precursor. It is therefore also necessary to explore the duration and nature of 'tectonic episodes', and how they change one into the next. Does the Reelfoot Fault move once every ten million years, or is the current tectonic regime of North America young, perhaps younger than a million years?

It could be argued that more important than the seismic cycle of individual faults is the return period of highest intensity shaking in a given region. In many regions this may be an order of magnitude shorter than the individual fault recurrence interval. Such a period also has the advantage of being retrievable from secondary effects related to ground shaking, such as submarine slumps or sandboils. Recent work in the coastal plains of South Carolina (Obermeir et al. 1985) has succeeded in identifying the recurrence of ground shaking from the mapping of prehistoric sand-blows, such as were found after the 1886 Charleston event. That this is recording a phenomenon different from the true seismic cycle is suggested by the different geographical range of the liquefaction from the palaeo-seismic events. The failure to find definitive and unambiguous evidence for the fault that moved to cause the 1886 event, strongly suggests that like the Reelfoot Fault, the post Mesozoic displacement along the structure has been low, and the recurrence of individual 1886 displacements relatively long, or the current tectonic episode relatively young.

After discussion of the time frame of the seismic cycle, the next question is the significance of the historical and instrumental record of seismicity for indicating the whole pattern of coseismic deformation that would be revealed over the duration of a seismic cycle. The historical record for Eastern Canada, at best 300 years long, represents one thousandth of the duration of the seismic cycle, and is therefore a highly underexposed image.

2.1 Extending the historical database

North West Europe has a number of advantages in addressing the issues of intraplate seismotectonics. First it has a historical record of seismicity that extends back a millenium, and for the central region is complete for larger events (M>5) for around 800 years, and for lesser events (M>4), for around 400 years. Second, the subsurface geology both onland and offshore can be mapped from surface exposure and seismic reflection data, to show the configuration of faulting affecting sediments that over wide areas are younger than 50 million years.

Among plate boundaries and highly active intraplate regions it is possible to find a variety of different patterns of seismicity. There are regions in which microseismicity determined instrumentally mimics the distribution of historical earthquakes; there are however regions in which there is no effective micro-activity, just infrequent very large events (e.g. S. Chile and E. Sicily). There are regions in which there are marked geographical shifts in the seismicity (Iran, China). There are regions such as Turkey where there are marked temporal variations in overall seismic energy release across large areas. All these patterns can be seen because of an extended historical record that is probably in all these cases at least 10% of the seismic cycle. Do similar patterns exist within the more slowly deforming continental intraplate regions, operating over a longer time scale?

2.2 Spatial variations in seismicity

The cumulative deformation (location and magnitude) for a long seismic cycle, continental intraplate region cannot readily be extrapolated from current seismicity. While the geological manifestation of this deformation does provide a compound picture of the total seismic cycle, in general, fault displacements do not tend to pass through to the surface, or if so, they tend to be indistinguishable from older movements. Over tens of thousands of years, fault scarps simply become eroded away. Only for extensional terrains is the preservation of faulting very high. Normal fault displacements also pass through to the surface for lower earthquake magnitudes than reverse faults.

Extension within the continental intraplate setting is however rare (Sykes & Sbar 1974). One such intraplate extensional environment lies in the centre of North West Europe, around the Lower Rhine, on the border between Holland and West Germany. In this region, it is possible to compare the geological manifestation of the deformation associated with the total seismic cycle, with the seismicity obtained both from short periods of instrumental monitoring and from the historical record.

In figures 1 to 3, the seismicity of the Lower Rhine Graben is shown over three time periods. Six years micro-seismic monitoring (M>1) (Fig.1) can be compared with almost five hundred years historical seismicity (M>4) (Fig.2), and a projected 100,000 year seismicity (M>6) (Fig.3). The 100,000 year map has been constructed from consideration of the total Quaternary fault displacement (up to 80m) taken from Ahorner (1962). The consistency of displacement along the main faults, and the fact that they broke surface at all, strongly suggest that these Quaternary faults were associated with major earthquake-generating fault movements. Magnitudes have been assigned according to fault length and fault displacement scaling relationships compiled by Bonilla et al. (1984), adjusted for approximately 5% of the Quaternary period. As one example, the Horremer-Sprung - Erft-Sprung - Swist-Sprung fault system running to the west of Koln, is about 35km long, and the 100,000 year offset of about 4m scales to one magnitude 7 earthquake in this period. Fig.3 is not of course intended as an exact prediction, but rather an illustration of the seismicity within this area in a time period approximating to the seismic cycle of the major faults.

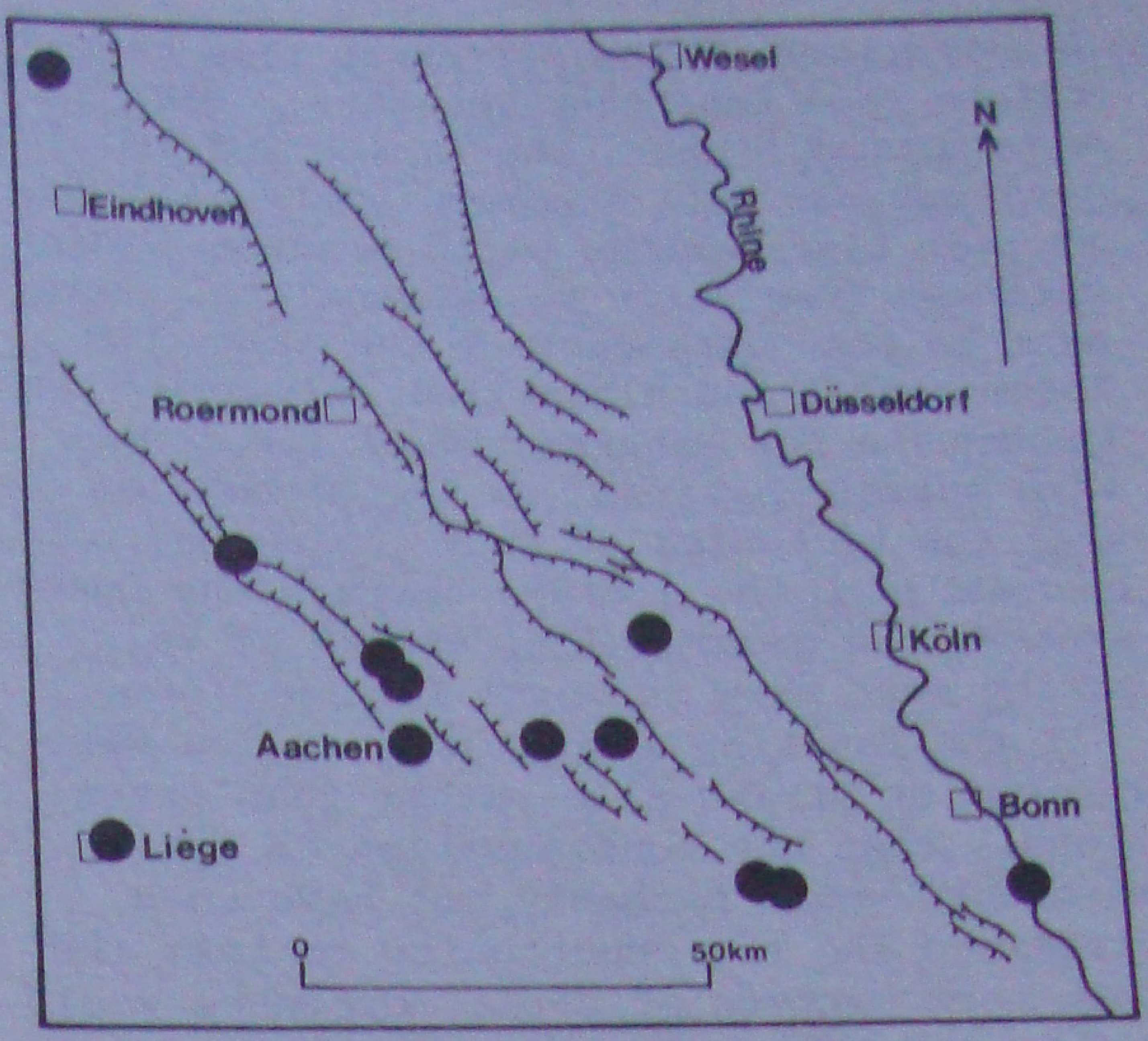

Figure 2: Lower Rhine Graben historical seismicity (M>4) 1500 to 1980

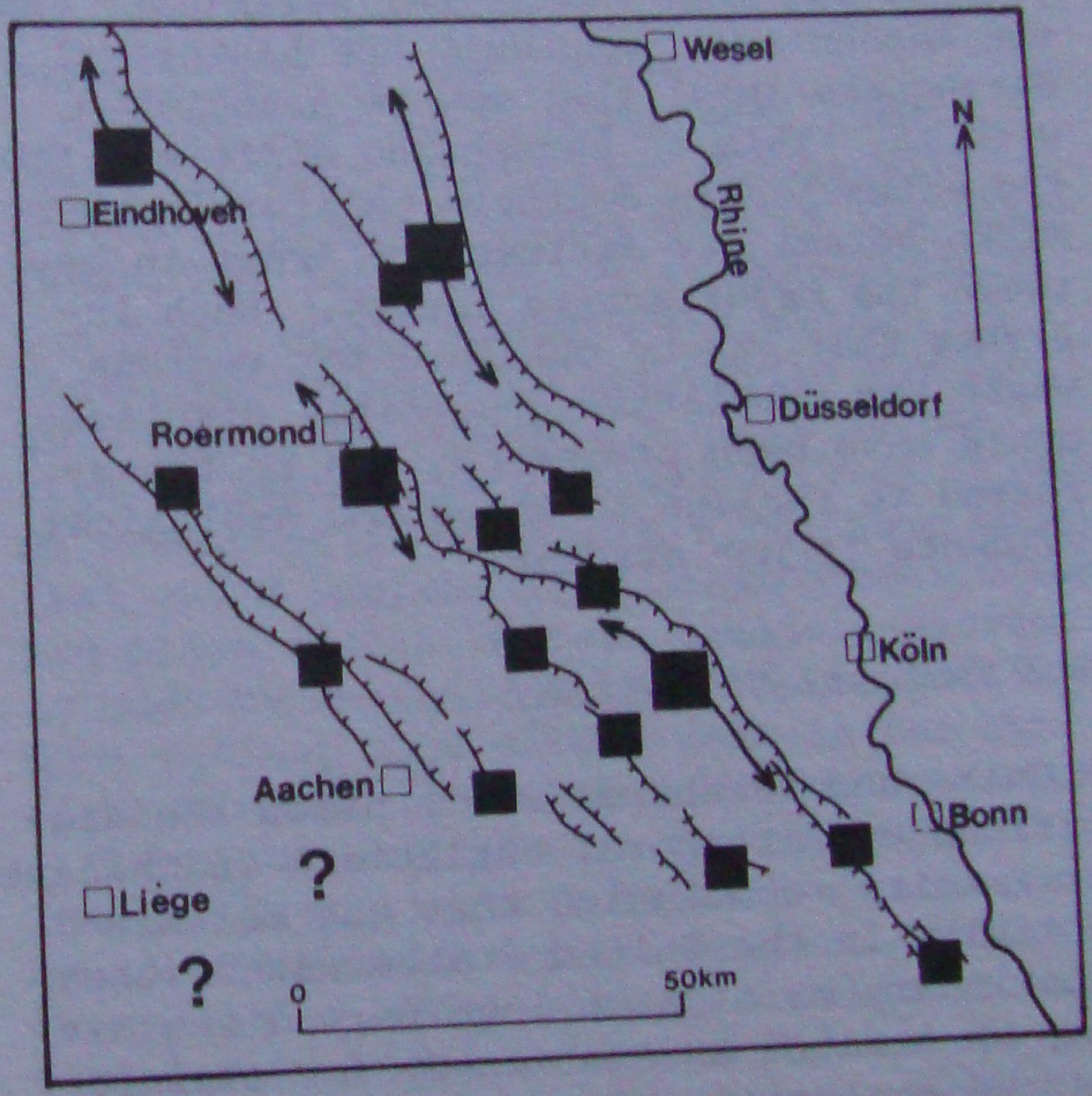

Figure 3: Lower Rhine Graben 100,000 year seismicity reconstructed from surface fault displacement. (Large squares: M>7; small squares: M>6)

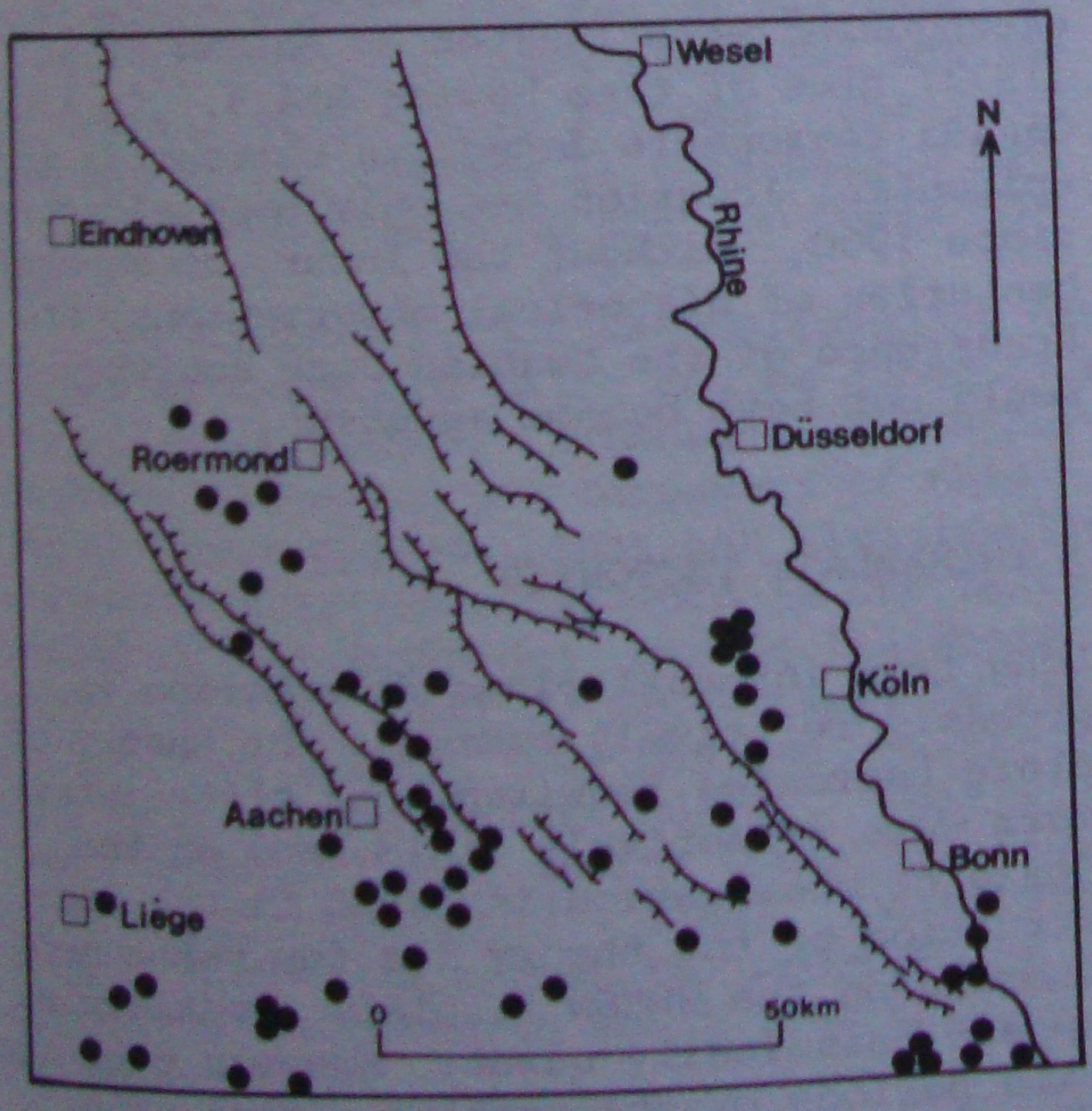

Figure 1: Lower Rhine Graben micro-activity (M>1) 1976 - 1982 (after Ahorner 1983)

A comparison of the different time periods offers some important insights. For the area around Aachen, the 6, 400 and 100,000 year periods tell a common story, and the shorter time periods would provide a good database from which to extrapolate. However to the north-east of the area, the instrumental and historical seismicity is inadequate for assessments of the longer term seismic hazard. On the assumption that the tectonics of this region has not changed from the average through the Quaternary, the geographical spread of seismicity must show temporal fluctuations.

If the faulting across this region were reverse or strike-slip rather than extensional, then the configuration of fault movements would probably not have been preserved and the opportunity to test the long term pattern of fault movements would not be possible. Such is the situation in the majority of intraplate continental environments.

Along the Rhine Graben, the eastern margin of the graben is the fault with the greatest known Quaternary displacement in North West Europe - 350m at Heidelberg, yet has far less historical seismicity than the Aachen area, and only one historical earthquake (M>4) that may be associated with it. This is perhaps no different from the situation in Southern California where micro-seismicity defines the areas in between the major active faults. Such insights that can be obtained for regions where the cumulative geological displacements have been preserved, can be transferred to regions in which the geological evidence is not evident.

2.3 Temporal Variations

McGuire and Barnhard (1981) noted the significance of temporal variations in Chinese seismicity, concluding that the seismic activity in the United States was 'either stationary or of such long period that it may be treated as stationary for seismic hazard analysis'. In Northern Scandinavia, temporal variations in seismic energy release are manifest in the existence of a series of parallel reverse fault scarps that formed around 9000 years ago. These scarps are parallel to one another, and trend NNE - SSW. The longest of these runs for 150km with a displacement of from 5 to 10m (lagerbäck 1979). In the same general area as the fault scarps, there are widespread giant landslides formed on low gradients in glacial till, that have also been dated as being contemporary with the fault scarps. From displacement-length scaling relations these fault scarps were probably associated with earthquakes at least M 7.5. The current seismicity of the region is low, with a few small instrumental and historical earthquakes.

Clearly the seismic energy release in Northern Scandinavia 9000 years ago was several orders of magnitude higher than it is today. While explanations that associate these faults with the early stages of rebound are likely to be correct, they nonetheless demonstrate an underlying tectonic control. Not only are they parallel to one another, and orthogonal to the maximum horizontal stress direction for the region, but they also run parallel with compressional inversion structures seen in the offshore continental shelf to the west, that were active through the Neogene, and in at least one instance as late as the Pliocene-Quaternary. For seismic hazard assessment in Northern Sweden, whether short or long term, these faults pose an awkward quandary.

The most notable temporal fluctuation in seismicity levels in the past century in North West Europe is in the Swabian Jura, Southern Germany, where in one small region, after several centuries of seismic silence, earthquakes began around 1880. Shocks in 1911 and 1943 were M 5.5, and in 1978 M 5.3, with numerous smaller shocks and aftershocks, along an intersecting NNE - SSW and NW - SE set of strike-slip faults. The seismicity level of this small area has over the past century been equivalent to a similar sized region of Southern California.

In Northern Canada, the Bryan Martin Channel burst into activity in 1972, and between November 1972 and January 1973, 74 earthquakes were located by Basham et al. (1977) nine of them having M>4.5. In Arctic Canada reasonable detection thresholds and epicentral location has only been effective since 1960. Without the luxury of several centuries of historical observations, the transience of the Swabian Jura activity would not have become apparent.

3 INTRAPLATE TECTONICS

Long term internal plate deformation is probably relatively common. The theory of plate tectonics required that plate interiors were effectively rigid, and on the scale of observation involved in the construction of the theory (a few years monitoring on the WWSSN), plate interiors do appear seismically quiet. However over long time periods of observation across many continental intraplate regions, there is seismicity and crustal deformation.

Complex zones of intraplate deformation may operate at a variety of rates and over a variety of time periods. They may represent intercommunication across plates (effectively slow plate boundaries), membrane tectonics as plates change latitude across the geoid, or differential movements between the plate and underlying mantle. As the geometry of rigid plate motions can never gear directly with that of rising and falling convection cells in the underlying asthenosphere, it is inevitable that contrary motions exist beneath a plate, that minor upwellings may occur mid-plate, and that internal deformation leads to seismicity.

Slow rates of deformation, with infrequent surface fault-scarp formation may be hard to locate in the surface morphology of emerged continents. It is only in regions of subsidence that the record of deformation has a chance of being preserved, and dated. The existence of a number of basins, and the slowly subsiding shelf regions can be studied across North West Europe to provide a picture of the tectonic development through the Tertiary.

This indicates phases of tectonic disturbance - of intercommunication between the Alpine collision zone and the North Atlantic spreading ridge, which continued from the beginning of the Eocene through to the end of the Oligocene, and involved about 5 to 10km N-S compression and a corresponding E-W extension, across the entire region. This deformation was concentrated along extensional rifts such as the Rhine Graben, and across compressional fold belts with underlying reverse faults, as across Southern England. The region was also criss-crossed with NE-SW sinistral and NW-SE dextral strike-slip systems. The areal seismic energy release at this period may have been equivalent to that of China today.

However this period was followed by new phases of tectonics which can be dated from the offshore region. Extension in the Lower Rhine Graben is one component of this new tectonic episode, that has also involved a renewed surge of subsidence in the Central Graben of the North Sea, and in the Moere Basin, off the coast of Mid-Norway, as well as regional uplifts over England, North-West Germany and Western Norway. This episode probably began in the Upper Pliocene or Lower Quaternary (2 - 4 Ma). Continuing crustal extension across the Lower Rhine Graben has amounted to about 100m through the Quaternary.

In the absence of available subsided Tertiary basins onland in North America, deformation can generally only be dated as post-Cretaceous or even post-Triassic. This always gives an impression that the same tectonic environment has been operational for the past 50 million years. However from the evidence of the changing tectonic boundary conditions of the region to the west and north-east, this is relatively unlikely.

The Tertiary tectonics of Arctic Canada is far from being fully comprehended, as it represents a complex and changing zone of major crustal shear and compression, that operated through the Eocene and the Oligocene , parallel with a similar phase of compression tectonics across North West Europe. However from the Miocene in Arctic Canada compressional tectonics was replaced by extension (Miall 1984).

The regionally consistent stress fields across central USA passing into Eastern Canada suggests that seismicity is following a broad path of compressional deformation. The New Madrid earthquake that achieved about 1m of horizontal compression along a 50km fault, if repeated across a 1000km wide zone every two hundred years would achieve 250m of horizontal compression in a million years, across the whole Eastern part of the continent.

However just as in North West Europe where the major horizontal compressive stress is uniform across much of the continent, but swings by 90° in passing into the Moere Basin offshore Mid-Norway, so focal mechanisms from the Baffin Bay region appear to indicate a swing in the stress regime (Stein et al. 1979). It would be premature to construct a tectonic model that could explain all the deformation taking place across Eastern Canada. However it must be recognized that the seismicity does reflect slow alterations in the configuration of the North American continent.

The major obstacle to the recognition of intraplate tectonic deformation in Eastern Canada is the Ice Age heritage. As discussed below, deep glacial erosion of superficial formations and rapid fluctuations in sea-level and land-uplift from ice-cap formation and removal, all serve profoundly to obscure a relatively weak long term tectonic signal beneath a strong Ice Age noise. There is also a problem as to any contribution to the contemporary seismotectonics from the process of rebound itself.

4 SEISMICITY AND POST-GLACIAL REBOUND

Ever since the waning of the Laurentian ice-sheet, the underlying crust of the region has been rising. This rate of rebound was initially dependent both on the rate of unloading and the response of the underlying mantle. The most rapid period of unloading is generally considered to have occurred at the very end of the ice-sheet's existence, perhaps an order of magnitude faster than the rates pertaining today.

Rebound inevitably involves crustal deformation. The magnitude of this deformation does not correlate with the rate of uplift or even the gradient of uplift, but with the rate of change of gradient: the flexure of the crust. Deformation relating to rebound is superimposed on the deformation associated with tectonic forces. If a region is suffering tectonic deformation, then the two forces, one showing rapid decrease in effect with time, will interfere.

There are a number of ways in which this interference can operate over time, and in different azimuths relative to the regional stress regime, around and across the rebound dome. An attempt to find a correlation between seismicity and rebound in Eastern Canada is unlikely to succeed because of the sprawling nature of the rebound, and the evidence from the existence of a regional stress regime extending far beyond the borders of the ice-cap, that there is an underlying intraplate tectonic control to seismicity.

However every earthquake in Eastern Canada may have some component of the stress that is released attributable to crustal deformation associated with rebound. In Fennoscandia, the seismicity is generally disposed across the area of rebound, but evidence from offshore indicates a tectonic component to much of the seismicity. Focal mechanisms for earthquakes on the margin of Western Norway show compressional solutions that correspond better with rebound marginal deformation than with the background tectonic stress regimes found onland or offshore (Havskov & Bungum 1986). The ideal laboratory for testing the contribution of rebound doming to seismicity may be Scotland, where the uplift is isolated. In this region the location of seismic activity does appear to correlate relatively closely with the location of the dome. Pre-existing faults are being reactivated as they are expedient for local stress release within the crustal dome. Total uplift may be around 150m.

Rebound related tectonics can create problems with the assumption of temporal continuity of seismic energy release. Around the centres of rebound domes, where the crust was deforming most rapidly soon after the ice-cap disappeared, seismic activity was probably higher than today. Evidence for post-glacial faulting requires special consideration in the assessment of seismic hazard.

5 SEISMOTECTONICS AND SEISMIC HAZARD

In the knowledge that historical seismicity provides an incomplete foundation on which to build seismic hazard procedures in Eastern Canada, the question of broadening the database becomes urgent.

First this may be achieved through an extension of the historical database to include searches for prehistoric evidence of ground shaking. A study of the secondary effects of seismicity such as lake slumps, sand-blows and submarine slides, can all potentially record past strong ground shaking. An important programme of lake-bottom studies, has already provided evidence of features associated with past earthquakes in Eastern Canada (Larocque & Shilts 1986). A major earthquake on the Scotian Shelf between 5000 and 12000 years ago was proposed on the basis of a submarine slump studied by Piper et al. (1985). Such studies can hope to reveal the all important evidence for the location of the larger earthquakes in Eastern Canada.

A second method of broadening the database is through a process of pattern recognition. If the nature of a significant earthquake-generating fault movement can be identified, then other comparable structures can be sought. Such work has been successfully undertaken around the Mississippi Valley to identify uplifts, similar to the Reelfoot Uplift, which was formed in the New Madrid earthquakes of 1811 - 1812. In Canada, the beginnings of such an approach can be found within the work of Forsyth (1981). The 1935 M 6.2 Temiskaming earthquake in Western Quebec and the 1944 M 5.7 Cornwall Massena earthquake lie in a zone of WNW - ESE oriented faults that can be followed through to Montreal and which have evidence for recurrent movement along them into post Lower Cretaceous times. Within the regional stress regime as attested both by focal mechanisms and in situ stress determinations, such faults would be reverse faults, with some strike-slip component corresponding with the orientation of other known surface fault breaks found far to the south-east in Oklahoma, Tennessee and Kentucky. Background microseismicity in Western Quebec is concentrated to the north of the WNW faults on older Grenville terrain, in which individual surface faults have not been mapped. Microseismicity may not correlate with larger events: it is a plausible and testable hypothesis that faults within the WNW fault zone are active, and capable of generating earthquakes the size of that at Temiskaming or larger.

A third approach to broadening the database involves the detailed investigation of the offshore geology to unravel the evolving tectonics through the Tertiary. Intraplate tectonics may be relatively small scale compared with the major phases of rifting that formed the Atlantic margins, but it is nonetheless regionally consistent. Offshore horizons through the Tertiary have generally been dated as part of well logging during hydrocarbon prospecting, and this information allows fault histories to be mapped through the Tertiary and into the Quaternary. From this it is possible to find the duration and configuration of contemporary crustal deformation.

6 SEISMIC GROUND MOTION

The dearth of earthquake strong-motion data recorded in the intraplate environments of Eastern Canada and North West Europe has forced a reluctant dependence on surrogate data from regions of higher activity such as California and Italy. The engineering reliance on Californian strong-motion data intrudes into the specification of general guidelines for design response spectra: the American Petroleum Institute (1981) recommends zonal effective acceleration scaling factors for different offshore American coastal waters, but makes no such distinction with the response spectra. The degree of validity of using such data for engineering design purposes is a key issue, but one that cannot easily be resolved within the framework of strong-motion data alone, because of the paucity of local records.

Factors which contribute to regional ground motion variation are local crustal geology, fault geometry and seismic source dynamics. With the obvious difference in tectonics between Western and Eastern USA, evidence for attributable variations in seismic source characteristics has been sought by a number of means. Kanamori & Allen (1986) suggest that the average stress drop is correlated with earthquake repeat time through a dependence on slip rate. With a factor of five difference commonly observed between the static stress drops of earthquakes which occur with short and long recurrence intervals, the extremely long repeat times of earthquakes in intraplate regions such as Eastern USA are conjectured to indicate high average stress drops. Scholz et al. (1986) obtain a similar result in studying non-plate boundary Western USA events.

Studies of static stress drop based on correlations of seismic moment with fault length, adduced from surface rupture and aftershock zone dimensions, are however less relevant for understanding ground motion than studies of dynamic stress drop based on correlations of seismic moment with source duration. Studies of this kind involving waveform modelling, have been carried out (Somerville 1986) for a database of events from Western USA, Eastern USA and Canada, and intraplate regions such as Western Australia, West Africa and South Africa. In contrast with the static stress drop investigations, no significant difference between interplate and intraplate results could be identified with the data available. Whether or not this observation survives the acquisition and analysis of further data, it does spotlight the need to examine the effects of local crustal geology and fault geometry on ground motion variability.

A sensitivity study aimed at discerning these effects has been carried out using a suite of programs written by Spudich at USGS. A review of techniques for the numerical modelling of extended seismic sources is given by Spudich and Archuleta (1986), which includes the main references on the discrete wavenumber finite element method implemented in the Spudich codes.

Whatever differences there may be in seismic source characteristics, between one region and another, the effects of variations in the dynamical properties of base rock, and of variations in depth of faulting in themselves are sufficient to cause important differences in ground motion. Such effects are all too readily masked by loose definitions of base rock: the American Petroleum Institute (API) quote a figure of 914 m/sec for shear wave velocity, which is considerably lower than the 2500 m/sec figure adopted in Japan, which corresponds to relatively hard rock layers.

In the low frequency range relevant for offshore structures, differences in base rock and depth of faulting could lead to differences in ground motion of a factor of several times. This demonstrates the importance of site-specific seismic hazard assessment which recognizes the potential for significant variations in ground motion between sites in the same tectonic province. It also establishes a principle for the selection of foreign strong-motion data used to construct seismic design spectra. Records should be discriminated on the grounds of quality of base rock, and care should be taken with records from sites of uncertain geotechnical provenance.

7 CONCLUSIONS

At plate boundaries, the highest hazard is recognized as being located at those regions that have not recently (historically) witnessed a major earthquake. In contrast intraplate seismic hazard is conventionally indicated as being greatest exactly where epicentres of historical earthquakes have been identified. This ad hoc method of designating intraplate seismic hazard may be practical and simple, but it may also have little scientific foundation.

Investigations in the active Basin and Range of Western USA have shown that a number of faults such as the Wasatch Front have had no significant historical seismicity and yet demonstrate major prehistoric fault displacements. Now the Meers fault in Oklahoma, which is located in the continental intraplate province of North America (a province that continues into Eastern Canada) has several metres of Holocene displacement but no known historical or instrumental seismicity (Kerr 1985). If the historical record is an inadequate foundation on which to base seismic hazard in fairly rapidly deforming Western USA, then how much more inadequate may it be in Eastern North America?

The more that is learnt about intraplate seismicity, the more it appears to be little different from plate boundary seismicity slowed down in time. Even the intraplate zones of deformation, such as the band of compression passing across North America, may be little more than very slow collision zones. In passing from areas of high activity to continental intraplate regions, as the seismic cycle lengthens, more and more of the requisite information is going to lie in the geological record rather than in the historical or instrumental record.

Establishing conservative parameters of the seismic hazard within regions where there has been pronounced historical seismicity is comparatively straightforward. The challenge is to identify high seismic hazard in areas that have failed to show any concentration of historical seismicity. This does not just apply to intraplate areas but also to some of the slower plate boundaries (e.g. see Adams 1984) such as the Western coast of Vancouver Island and the coasts of Washington and Oregon where a major subduction zone earthquake may have had only prehistoric precursors.

Seismic zonation in Eastern Canada has already retrospectively had to cope with the 1929 Grand Banks earthquake, the largest in the region and yet one that appears isolated. In the absence of any explanation for either the location or the size of the earthquake, a neat diamond shaped fence has been erected around it in seismic hazard maps (Basham et al. 1985). While the authors must be aware of the uncertainties of such a designation, those who use such hazard maps may well not be so informed. While it may be easier to incorporate the geological evidence into probabilistic site specific hazard models as undertaken for nuclear installations, offshore platforms, etc., it remains an open challenge to produce seismic zonation maps for Eastern Canada that do not simply fence off historical earthquakes, but attempt to place them in the context of the seismic cycle. Unless the reason for the location and return period of the largest earthquake in Eastern Canada can be established, the construction of fenced off hazard zones will always lack a scientific rationale. At present expediency and conservatism are an interim substitute.

Historically seismic hazard methodologies adapt to the arrival of the unexpected. The absence of major damaging earthquakes in Eastern Canada over the past decade has allowed existing hazard methodologies to survive unchallenged. The next generation of seismic hazard maps must develop ahead of the arrival of unexpected earthquakes, through the intelligent incorporation of geological information. It remains the joint task of geologists and seismologists to work towards this important objective.

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