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CAPE TOWN EARTHQUAKES: REVIEW OF THE HISTORICAL RECORD

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Abstract

The earthquake history of Cape Town, identified as a zone of seismic hazard on a mid-19th century global earthquake map, remains incomplete, vague, and often erroneous in the public memory. Before the Ceres-Tulbagh earthquake of 29 September 1969, the two largest historical earthquakes happened on 4 December 1809 and 2 June 1811. Detailed eyewitness descriptions establish that the common focus of these strong (magnitude ~6) events was only 20-30 km from the modern city centre, probably on a major shear structure identified, after Koeberg nuclear power-station investigations in the mid-1970s, as the Milnerton Fault. Future recurrence of strong earthquakes along this seismogenic feature is a major natural hazard in the Cape Town area, but seismic emergency planning is neglected in the current Metropolitan Structural Development Framework. The southernmost part of the African continent is on the brink of a zone of very slow deformation (relative motions of ~2 mm/yr) between the Nubia (NB) and Somalia (SM) plates. The earthquake potential of this wide NB-SM plate boundary constitutes a grave natural threat to national security and socio-economic stability in Southern and Eastern Africa. Earthquake anniversary commemoration and educational outreach programmes are means of raising public awareness of the danger and holding the relevant authorities accountable for its mitigation or "provention".

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Introduction

Following recent media reports of a small earthquake that was felt on the 19th May 2003 in the coastal region on the northern boundary of the Cape Town metropolitan area, it is appropriate to review the significant events in the seismic history of the city, with a view to arousing public awareness of a substantial earthquake hazard in this area. Commentary on this latest event reveals that public memory of the Cape Town's seismic history is poor, and mainly dominated by the relatively distant Tulbagh-Ceres event of 29th September 1969. There is almost no general recollection of much more proximate and dramatic events of 1809-1811, and of other earlier and later events that have been located close to the city, albeit erroneously in some cases.

In part, this ignorance is due to a lack of access to and modern re-interpretation of original archived records or historical reports about Cape Town earthquakes, a few of which are of considerable seismological value even to the present day. Among the earlier examples is an earthquake that occurred on 4th September 1695, which in the official seismic catalogue [1] of the South African Council for Geoscience (CGS) is recorded as having occurred on "1695/10/4", a numerical mistranscription of the month. There is even confusion about the time. The CGS catalogue, supported by the naturalist Von Buchenroder's account [2] in 1830, states that it occurred in the evening (circa 7 PM local time), whereas the historian Theal [3] says it happened during the morning.

In the CGS catalogue, coordinates of the epicentre – the surface point vertically above the earthquake focus - are given as 34,0°S 18,4°E, i.e., the rough location of Cape Town, for want of any better alternative. The event description (loud thunderous noise and trembling of the earth, but no damage to any structures) corresponds to a level of about IV (Roman numeral 4) on the Modified Mercalli (MM) intensity scale. This ordinal scale [4] is a standardised way of ranking, by values between I (one – not felt, but evidenced by long-period effects, e.g., swaying of doors or chandeliers, due to distant large magnitude earthquakes) and XII (twelve - nearly total destruction), the felt effects and types of damage experienced at a particular locality. Assuming that the earthquake focus was close to Cape Town, MM Intensity can be empirically translated into a modern instrumental ("Richter scale") magnitude of about 4.5. [1]

Of particular seismological interest in historical accounts is the duration of the shaking. Theal (ref. 3, p. 374) remarks that shaking lasted only a "few seconds", whereas Von Buchenroder (ref. 2, p. 25) notes that it "seemed to go towards the interior of the colony, and to be of longer duration in some places than in others". An unsourced duration of "100 seconds" is cited in some media accounts (cf. Cape Argus "Today in History" column, 4th September 1996). Duration is important because it is related to the location and size of the earthquake. A nearby earthquake in the magnitude range 4-5 would produce shaking that lasts just a few seconds. A duration of "100 seconds" indicates an earthquake of greater magnitude at a large distance from Cape Town, or possibly but less likely a swarm of smaller events occurring in close temporal succession.

The "Cape Town" earthquake of 14th August 1857, which had a 25-30 second duration [5] and similar MM Intensities (IV-V) in places as widely spaced as Cape Town, Genadendal, Paleisheuwel and Citrusdal, is a good example of serious location error in the CGS catalogue. [1] The latter assigns it the same epicentre as the 1695 event and an identical calculated magnitude. Analysing contemporary reports in the foundation Volume (No. 1) of the "Cape Argus", I established (1993 unpublished results) from the distribution of felt intensities that its epicentre was in the Ceres-Tulbagh area, and its magnitude was probably in the range 5.5-6.0; not quite as large as the magnitude 6.3 event on 29th September 1969 but definitely larger than the magnitude 5.3 event on 2nd March 1977. [6]

The 1857 earthquake is the first historical occurrence on the system of faults in the Ceres-Tulbagh area, a record previously held by an event on 9th October 1921 (reported in "The Argus" of 10 October 1921). [7] Whether or not a similar deduction about a distant epicentral location is possible for the 1695 event, is important to ascertain. If this earthquake did not have a distant focus, it provides useful information on the rate of recurrence of historical earthquakes that occurred on geological faults on the very doorstep of the Mother City.

In 1855, the Irish naturalist Robert Mallet - of whom the American seismologist Charles Richter (ref. 4, p. 30) writes that "no one man contributed more to the early organization of knowledge about earthquakes into a science" - published a global earthquake map under the auspices of the British Association for the Advancement of Science.[7] Cape Town is clearly shown as a zone of enhanced seismicity (Fig. 1), a reputation consequent on the strong events on 4 December 1809 and 2 June 1811.

Accounts of the 1809 and 1811 earthquakes

In 1830 W.L. von Buchenroder published a realistic eyewitness account [2] of the larger 1809 earthquake, for which the area of greatest structural damage - virtually complete destruction of the farmhouse - was on the farm Jan Biesjes Kraal, near modern Milnerton. (Older editions of the 1:50 000 topocadastral map series identify this property near the head of Milnerton Lagoon, in the area of the old Ascot Race Course and the new suburb of Milnerton Ridge.) Von Buchenroder’s stated purpose was “to preserve a faithful account of what was observed, particularly as from the propensity of man, to exaggerate any uncommon occurrence” (ref. 2, p. 18).

He visited Jan Biesjes Kraal and “Blauweberg’s Valley” on 9 December 1809, having been told “the earth had opened, that volcanic eruptions had taken place, that craters had been formed, and that lava had issued” (ref. 2, p. 20; his own quotation marks for this excerpt). What was found “fell considerably short of what I expected from the wonderful accounts I had heard, yet was nevertheless remarkable and interesting”:

> “Near the Kraal I found rents and fissures in the ground, one of which I followed for about the extent of a mile. In some places they were more than an inch wide, and in others much less. In many places I was able to push into them, in a perpendicular direction, a switch to its full length, of three or four feet. By the people residing in the vicinity, I was informed, that they had observed these fissures on the morning of the 5th December, in some instances three and four inches wide, and that one person had been able to push the whole length of an iron rod used to fix curtains upon them, and that others had been able to do the same with whip handles of even ten feet in length.”

From this and other information, the epicentre of the 1809 event is inferred to lie very close to Jan Biesjes Kraal, to the northeast of Cape Town central.

Burchell (ref. 8, p. 114-115) likewise gives an excellent eye-witness account of the 2 June 1811 event, from which precise deductions about its epicentre can be made:

> “ The weather, during the forenoon, had been warmer than usual; (the thermometer 75°) and the air was calm and perfectly tranquil. At this time I was in my room occupied in preparations for the journey: a part of the garrison, having been exercising on Green-Point, were returning to their barracks, when a sudden and violent explosion shook the whole house, with a noise as loud as that of a cannon fired close at the door. In three or four seconds after this, another report, still more violent and sharp, like the loudest clap of thunder, shook the building more forcibly than the first; and at the same moment I felt a strange and unusual motion. The atmosphere at that instant was agitated by a dreadful concussion.
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> “ The whole of this occurrence did not take up more than the time of five or six seconds; the day still continuing very fine and the sky perfectly cloudless. …”

This description of the 1811 Cape Town earthquake by an acute observer is of immense seismological value.

Richter notes: “… at short distances a single earthquake is felt by persons as two sharp jolts a few seconds apart. Such observations are so common that they led Davison to set up a special theory of twin earthquakes, now obsolete. ” (ref. 4, p. 27) Seismologically interpreted, Burchell’s description establishes an interval of "three or four seconds" between the impulsive arrivals of the P and S body-wave phases, immediately followed by "strange and unusual" (presumably lurching) ground motions of the surface ("L” and “R") wave train, not well developed at such short epicentral distance (Fig. 2).

The earliest historical record of a Cape Town earthquake, namely, that of General Augustin de Beaulieu, relating an event of 7 April 1620, is also remarkable in this context (ref. 9, p. 58):

> “ Tuesday, the 7th of April, found us at the same anchorage (~2 km SSW of Robben Island - CJHH), for lack of wind, though the rolling was still exceedingly great. At break of day there was a startling thunder-clap, followed immediately by another, which burst as though they had been cannon-shots, without any rumbling in the air as is usual with thunder.”

If the phrase "followed immediately by" in interpreted as meaning just a few seconds, perhaps only one or two, then the parallel with Burchell's account of almost two centuries later is striking. The double-jolt phenomenon evident in this record indicates that the focus of 1620 event was nearby, probably within a distance of 20 km from the observer

From detailed aftershock studies in the Ceres-Tulbagh area, [10] a P-S interval velocity of 8,52 km/s was empirically established, and may be assumed to apply elsewhere in the Western Cape. A 3-4 second interval between the two shocks translates into a distance of 26-34 km from Burchell's accommodation (the Lutheran pastorage in Cape Town) to the 1811 earthquake focus. Assuming the earthquake originated at a geologically usual focal depth of 10-15 km, the range to the epicentre is 21-32 km. Choosing a possibly more appropriate focal depth of 30 km, determined for the 1969 Ceres event by Shudofsky, [11] the maximum distance is only 16 km. The "Jan Biesjes Kraal" area is about 12 km north-east of Burchell's residence in 1811, and a 3-4 second P-S interval is entirely consistent with it being near the epicentre for an earthquake of slightly deeper than normal focus.

The 1811 earthquake had MM intensity of at least VI, but in most places VII, in the Cape Town area. The key phenomena associated with MM VI are: "Felt by all. Many frightened and run outdoors. … Weak plaster and masonry D cracked"; and those associated with MMI VII include: "… Damage to masonry D, including cracks. Weak chimneys broken at roof line. Fall of plaster, loose bricks, stones, tiles, cornices (also unbraced parapets and architectural ornaments …)" (after ref. 4, p. 137). In these definitions the term "masonry D" is formally defined as: "Weak materials, such as adobe; poor mortar; low standards of workmanship, weak horizontally".

Burchell (ref. 8, p. 114-5) describes the effect of the 1811 earthquake on the town's inhabitants:

> " I hastened out of doors to ascertain what had happened; but when I came into the street, and beheld all the inhabitants rushing out of their houses in wild disorder and fright; some pale and trembling, running up and down, unconscious whither they were going; mothers distracted at not finding their children with them; and every one with terror depicted in his countenance, crowding into the open street; when I beheld this, I instantly guessed that an earthquake had happened, for no answer could be got from those to whom I addressed the question; fright prevented their hearing what was said. … I believe that every individual inhabitant of Cape Town, men, women, and children, excepting those who from infirmity were unable to move, was, at that time, out in the street. There, all remained for at least an hour; and many for the whole day";

and further with reference to the effects of structural damage:

> " Walking afterwards about the town, … I was told that many houses were exceedingly rent, and some more materially damaged: but none were actually thrown down. At the mill, however, at Salt-river, the dwelling house, it was said, had received so much injury, that the owner considered it no longer safe or habitable. … Many of the ornamental urns which had escaped the earthquake of 1809, were now tumbled from the parapets down into the street: one on the top of the house where I resided, was shivered to pieces; and the wall of my bed-room was in the same instant divided by a crack which extended from the top of the house to the bottom."

In the case of the 1809 event, the occurrence of characteristic "sand blows", related to the sudden spurting of muddy water out of numerous small crater-like holes in the ground ("earthquake fountains"; ref. 4, p. 106-109), a vibration-induced liquefaction phenomenon, is another instance of exemplary reporting, here by Von Buchenroder (ref. 2, p. 21):

> " At Blauweberg's Valley, I found the sandy surface studded with innumerable holes, resembling in shape, but in nothing else, craters in miniature. These holes were from six inches, to a foot and a half, and some even three feet in diameter, and from four inches to a foot and a half deep; of a circular form, and the sides sloping to the centre. They were lined with a crust of bluish clay, of about a quarter of an inch in thickness, which had been baked by the sun, and according to its nature had cracked and curled up in fragments, which however adhered still to the sloping sides of the holes. …
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> " The appearance of the bluish baked clay, which had given rise to the story of lava ! was easily accounted for, from the rain (a great quantity of which had fallen in the preceding season) having been prevented by the substrata from penetrating and sinking deep into the ground, so that under the sandy surface, a considerable quantity of water had collected, in which a portion of the substratum of clay had become dissolved, and which had been forced up through the loose sand, by the concussions which took place.
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> " The people at Blauweberg's Valley, stated, that 'they saw jets of coloured water spout from these holes, to the height of six feet, in the night of the 4th of December, at the time that the shocks were felt'."

Richter (ref. 4, p. 139), commenting on his 1956 revision of the MM scale, records: "Ejection of sand and water, particularly in the form of earthquake fountains…, beginning at a small scale at (MM Intensity) VIII, becomes notable at (Intensity IX) provided that the necessary subsurface conditions exist."

A maximum MM Intensity (Imax) in the Milnerton area of not less than VIII to IX is obtained for the 1809 earthquake from Von Buchenroder, [2] and at least VII for the 1811 earthquake from Burchell. [8] From these data, a "felt magnitude" M_F (ref. 12, p. 116-117) can be obtained. To estimate the instrumental magnitude of historical South African earthquakes, Fernandez and Guzman [1] used the equation $M_F = 0.66 \times I_{max} + 1$. It is based on the simple numerical assumptions that: (i) the maximum MM Intensity XII corresponds to magnitude 9; (ii) there is a linear relationship between M_F and I_{max} expressed now in Arabic numeral form, from the lowest felt intensity for small magnitude events (i.e, $I_{max} = 2$, corresponding to $M_F = 2,3$) to the upper limiting MM Intensity XII. On this basis, the (revised) M_F magnitudes for the 1809 and 1811 events are 6.5 and 6.0, respectively.

Seismic hazard implications

Both the 1809 and 1811 earthquakes were due to sudden recurrence of slip along a plane of pre-existing crustal weakness. The likely seismogenic fault is a NW/SE-striking belt of sheared rocks along the coast at Bloubergstrand. [13] During pre-design investigations for the Koeberg nuclear power station, this fault was mapped in northwesterly direction about 8 km offshore from the nuclear site, and it certainly also extends in a southeasterly direction beneath the Milnerton area. The "Milnerton Fault" [14] may extend farther across the central Cape Flats and the north-eastern part of False Bay to a large fault exposed onland between Rooiels and Betty's Bay (Fig. 3).

If this correlation of the Milnerton and Rooiels faults is correct, then extensive newly-urbanised sectors of the Cape Flats in Mitchells Plain and Khayelitsha straddle an important seismogenic structure, which poses a threat to tens of thousands of citizens. In a review of the long seismic history of the Middle East, [15] Nur emphasizes that "Earthquakes don't kill people, buildings do", which news pictures and TV images from recent quakes in Turkey reiterate. Numerous news items report the evident failure of Turkish authorities to adequately enforce building regulations for earthquake-prone areas. In Athens, Greece, nearly 100 civil engineers, building contractors, and low-ranking town planning officials were put under investigation as part of a criminal probe into deaths caused by alleged substandard structures destroyed in a 1999 event.

The problem of seismic hazard in the Cape Town region is by no means a trivial one. Newly built houses on the Cape Flats have experienced structural damage during gale-force winter storms, and death, injury, and destruction was wreaked by the Manenberg-Guguletu “tornado” or “wind event” of 29th August 1999. Such experience requires the civic authorities to consider seriously what havoc can be wreaked by earthquake recurrence, even of relatively moderate size (magnitude ~5), along the Milnerton Fault. Many areas of low-cost urban development in areas such as Khayelitsha, overlying the water-logged parts of the “Cape Flats Aquifer”, may be quite literally death traps for their inhabitants. Some new business, entertainment, and sports-complex developments, such as Century City around the N1 national road, are also more or less directly on the postulated Milnerton fault-line. Yet the 1997 draft of the Cape Metropolitan Spatial Development Framework (MSDF) contains no mention of an earthquake problem in its chapter on “Natural Hazards”.

The 379-year historical record since the first recorded earthquake in the Cape Town area in 1620 [1,7,9] is not long enough to provide a representative sample of prior major events. Hence the importance of consolidating our knowledge of early seismic history, such as the 1695 and later shocks, in order to improve on estimates of the average recurrence time for quakes of different magnitudes. There is no seismotectonic reason to suppose that prehistoric earthquakes much larger than the 1809 and 1969 events have not already happened in the region, and may not recur in future.

Elevation of beach deposits in the Elands Bay-Saldanha Bay region, by 2-3 m above sea level during the past 4000 years, is interpreted in terms of a mid-Holocene sea level high-stand due to global palaeoclimatic factors. [16] A “neotectonic” explanation, involving a major earthquake and associated permanent ground deformation, is also possible; perhaps more probable than the palaeoclimatic theory, when better-known global sea-level curves are used as a reference standard, and when the nearby submarine evidence for continental margin instability [17] is considered. A quake in the magnitude range 7-8 is generally accompanied by coseismic fault slip of 3-4 m displacement. A time-averaged tectonic uplift rate of, say, 0,3 mm/yr takes just one magnitude 7 (normal- or thrust-fault slip) event every 10 000 years.

Augmentation of the seismic record requires specifically directed, multidisciplinary, collaborative research between geophysicists, geologists and archaeologists into the "palaeoseismology" of the

Cape metropolitan area, in order to extend it back by thousands of years into the Holocene period (last 10 000 years). Dr Graham Avery of the South African Museum has achieved some success, interpreting the seismogenic origin of rock-falls in prehistoric cave habitations (e.g., Die Kelders; G. Avery, personal communication, 1995). In engineering geological studies around the Milnerton Fault trace, it is crucial that relevant subsurface information – evidence of former earthquake fountains, for example - is not overlooked or misinterpreted through ignorance, and ultimately irrevocably lost through inadequate geological record-keeping prior to site excavations.

African plate tectonic context

In the 30-odd years since the 1969 Ceres-Tulbagh earthquake, which occurred when the "plate tectonics revolution in Earth Science" had barely begun, much has been learned about the origins of these natural events and their driving forces. Earthquakes in Southern Africa arise because, over the last 11 million years at least, the western and eastern parts of the African Plate are separating along one of the earth's largest developing extensional structures, namely, the great East African Rift System (EARS). The EARS itself - with its dramatic fault scarps, flanking mountains, volcanoes and great lake systems - is the most conspicuous feature among a number of tectonically active physiographic elements within the "diffuse plate boundary" [18] between the Nubia (NB) and Somalia (SM) plates (Figure 4). In a nascent form the NB-SM plate boundary also extends through the Republic of South Africa. [19-20]

During the previous century, at least two earthquakes substantially greater than magnitude 7 have occurred along more northerly parts of the EARS. [21-22] At the southern end of Lake Malawi, surface rupture along the youthful Bilila-Mtakataka fault scarp for an average slip of ~10 m over 100 km length, occurring during a probable magnitude 8 event. [23] Closer to Cape Town, in the area around the Toorwater hot spring between De Rust and Willowmore, another ~100 km-long, youthful fault-scarp with ~4 m surface displacement, [24] bears testimony to a prehistoric Southern Cape earthquake of magnitude ~7.5.

In the light of the available evidence, the NB-SM plate boundary zone arguably poses a great long-term threat to South African national security, and the socio-economic stability of many other potentially affected countries in the Southern African Development Community (SADC) region. In whatever SADC country the next major (magnitude 7+) to great (magnitude 8+) earthquake or "big one" occurs, its effects on population and infrastructure will likely be as destructive and devastating over a wide area as those of a powerful nuclear bomb.

Public earthquake awareness and emergency planning

Strong earthquakes of magnitude 6 or greater will inevitably recur along the Milnerton Fault. It is therefore important to raise public awareness of the seismic hazard issue, both at the grass-roots community level, and at the higher, decision-taking level of metropolitan councillors and civic planners:

> "Community and individual involvement in the hazard management process is dependent upon a greater general awareness of natural hazards (eg location, extent, severity) and the steps that can be taken at the local level to minimize their impact. Geoscientists and those concerned with promoting safe development clearly have a role to play in helping to foster such awareness, by developing mechanisms for communicating essential earth-science information in formats that are accessible to the non-geoscientist" (ref. 25, p. 7).

In the Western Cape, the need is not for the sophisticated high technology, such as prediction research or early-warning systems, adopted in places such as California, Mexico, or Japan, where the seismic hazard is both more overt and much greater. What is required is "better community preparedness (my emphasis) to live with earthquakes so that the need to 'predict' is reduced". [25]

There was no overt commemoration of the 30th anniversary of the Ceres-Tulbagh event in 1999, reflecting a serious lack of public awareness. A reminder that a similar earthquake also happened nearly 200 years ago closer to Cape Town, and will inevitably happen here again, is one step to encourage better civic preparedness. The formal declaration of 4 December as annual "Cape Town Earthquake Awareness Day", looking towards a bicentennial in 2009, could be considered. In addition to 29 September, there are other dates of significant South African earthquakes that may serve as equivalent reminders for other large towns and cities throughout the country.

In the 1992 Dahshur (northern Egypt) earthquake (541 fatalities), "a considerable number of schoolchildren died as a result of panic reaction and crushing in school buildings that were never in any danger of collapse - nor liable to collapse in any earthquake likely to occur in the country" (ref. 25, p. 8). This tragedy highlights the intrinsic importance of stimulating community awareness by reaching out to the youth, targeting the impressionable school-going section of the community to increase their knowledge of seismic processes.

The panic of Cape Town inhabitants immediately after the 1811 earthquake is described by Burchell (ref. 8, p. 115):

> "As soon as this conviction (of an earthquake happening) gains possession of the mind, our sensations, which, till then, may have been only those of surprise, assume a new and peculiar character. To those born in a country where these convulsions of nature happen frequently, such an occurrence as this may perhaps occasion little uneasiness; but to others who, for the first time in their lives, feel that the ground they walk upon is not immoveable, an earthquake, with all the dangers which may possibly accompany it, is an event which cannot fail to excite considerable alarm. Everybody stood for a while in dreadful expectation of the catastrophe."

The death or serious injury of young schoolchildren in panic-induced crushes, as happened near Cairo in 1992, is but one potential consequence of a future Cape Town earthquake. Should it occur during school hours, the actual failure of numerous poorly founded and ill-constructed school buildings would be far more serious. (A number of Cape Flats schools were seriously damaged in the windstorm event in the early morning of Sunday 29 August 1999.)

After the March 1933 earthquake (magnitude 6.2) in Long Beach, California, brick schools in Los Angeles suffered extensive damage, and a carnage of schoolchildren was avoided only because the quake struck in the evening, after schools had closed. Relying on photos and graphic accounts of actual damage, women's clubs and other concerned citizens, seismologists, and engineers, pressured the California legislature – over the opposition of vested business interests – to enact a law requiring school buildings to have a degree of earthquake resistance. [26] This example illustrates that "geologic knowledge held by specialists can only produce widespread benefits when it becomes applied through the actions of an informed public". [27]

The reactor at the Koeberg nuclear power station is built upon an aseismic raft designed – on the basis of a mid-1970s hazard study - to withstand a magnitude 7 earthquake at a focal distance of about 10 km. How many schools and other key facilities close to the trace of the Milnerton Fault are designed to these rigorous standards? And, if none, why not? One reason immediately suggests itself: As its omission from the draft 1997 MSDF document shows, no formalised contingency planning currently exists for a repeat earthquake disaster of the same magnitude as 1809-1811.

What about emergency services (hospitals, clinics, ambulance and fire stations) that should be expected to operate unimpeded through Cape Town's next serious earthquake (which could occur at any time in the future, even tomorrow)? If a critical risk analysis were done, it would probably find that emergency services are completely paralysed by a magnitude 6 quake. How many of the N1, N2 national-road bridges, and other main-road overpasses are felled across the main access routes for fire engines and ambulances (those that were lucky not to be already demolished in their fallen stations)? What about water- and power-supply infrastructure that necessarily crosses the Milnerton Fault trace? How do major hospitals and clinics of the Cape Peninsula operate in the absence of these essential services (and probably also many of their staff)?

All the above – and others yet to be articulated - are questions of great civic importance. A better-informed general public should insist on adequate answers.

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REFERENCES

1. Fernandez L.M. and Guzman J.A. (1979). Seismic history of Southern Africa. *Geol. Surv. S. Afr., Seism. Ser.* **9**, 78 pp.
2. Von Buchenroder W.L. (1830). An account of the earthquake which occurred at the Cape of Good Hope, during the month of December 1809; etc. *S. Afr. Quart. Jnl* **1**, 18-25.
3. Theal, G.M. (1922). *History of Africa South of the Zambesi, etc.: Vol.* II (Third ed.). George Allen and Unwin, Ltd, London.
4. Richter C.F. (1958). *Elementary Seismology*. W.H. Freeman and Company, San Francisco, 768 pp.
5. Morton P. (1857). Notes on the earthquake. *Cape Monthly Mag.* **2**, 253-255.
6. Fernandez L.M. and Labuschange P.G.A. (1980). Catalogue of earthquakes in Southern Africa and surrounding oceans for 1977. *Geol. Surv. S. Afr., Seism. Ser.* **11**, 32 pp.
7. Theron J.N. (1974). The seismic history of the Southwestern Cape Province. *Geol. Surv. S. Afr., Seism. Ser.* **4**, 12-18.
8. Burchell W.J. (1822). *Travels in the Interior of Southern Africa: Vol. 1.* The Batchworth Press, London.
9. Strangman E. (1936). *Early French Callers at the Cape* (Chapter on Augustin de Beaulieu). Juta & Co. Ltd, p. 43-71.
10. Green R.W. and Bloch S. (1969). The Ceres, South African earthquake of September 29, 1969: I. Report on some aftershocks. *Bull. Seism. Soc. Amer.* **61**, 851-859.
11. Shudofsky G.N. (1985). Source mechanism and focal depths of East African earthquakes using Rayleigh-wave inversion and body-wave modelling. *Geophys. J. Roy. astr. Soc.* **83**, 563-614.
12. Ambraseys N.N., Melville C.P. and Adams R.D. (1994). *The Seismicity of Egypt, Arabia, and the Red Sea: A Historical Review*. Cambridge University Press, 181 pp.
13. Von Veh M.W. (1983). Aspects of sedimentation, structure and tectonic evolution in the Tygerberg Terrane, southwestern Cape Province. *Bull Precambr. Res. Unit, Univ. Cape Town* **32**, 88 pp.
14. Andreoli M.A.G. Van der Vlugt R., Norman N. Von Veh M.W. and Andersen N.J.B. (1989). Interpretative Geological Map of the pre-Tertiary basement between Gansbaai and Waenhuiskrans-Arniston, S. Cape. Annexure to: *Geology of the Coastal Strip between Gansbaai and Waenhuiskrans*. Atomic Energy Corp. Rept. PIN 1133 (B/R)-GEA 848.
15. Nur A. (1991). And the walls came tumbling down. *New Scientist* (6 July issue), p. 45-48.
16. Miller D.E., Yates R.J., Parkington J.E. and Vogel J.C. (1993). Radiocarbon-dated evidence relating to a mid-Holocene relative high sea level on the south-western Cape coast, South Africa. *S. Afr. J. Sci.* **89**, 35-44.
17. Dingle R.V. (1980). Large allochthonous sediment masses and their role in the construction of the continental rise and slope off southwestern Africa. *Mar. Geol.* **37**, 333-354.
18. Gordon R.G. (1998). The plate tectonic approximation: Plate nonrigidity, diffuse plate boundaries, and global plate reconstructions. *Annu. Rev. Earth planet. Sci.* **26**, 615-642.
19. Hartnady C.J.H. (1990). Seismicity and plate boundary evolution in southeastern Africa. *S. Afr. J. Geol.* **93**, 473-484.
20. Hartnady C.J.H. (2002). Earthquake hazard in Africa: perspectives on the Nubia-Somalia boundary. *S. Afr. J. Sci.* **98**, 425-428.
21. Ambraseys N.N. (1991). The Rukwa earthquake of 13 December 1910 in East Africa. *Terra Nova* **3**, 203-208.
22. Girdler R.W. and McConnell D.A. (1994). The 1990 to 1991 Sudan earthquake sequence and the extent of the East African Rift System. *Science* **264**, 67-70.
23. Jackson J. and Blenkinsop T. (1997). The Bilila-Mtakataka fault in Malawi: An active, 100 km long, normal fault segment in thick seismogenic crust. *Tectonics* **16**, 137-150.
24. Hill R.S. (1988). Quaternary faulting in the south-eastern Cape Province. *S. Afr. J. Geol.* **91**, 399-403.
25. Degg M. and Ibrahim H. (1995). Geoeducation and the International Decade for Natural Disaster Reduction. *Geoscientist* **5** (No. 4), 7-8.
26. Geschwind C.-H. (1997). 1920s prediction reveals some pitfalls of earthquake forecasting. *Eos (Trans. Amer. Geophys. Un.)* **78**, 401 & 410-411.
27. Nuhfer E.B. (1994). Geologic hazards and educational outreach. *Geotimes* **39** (No. 1), 16-18.

FIGURE CAPTIONS

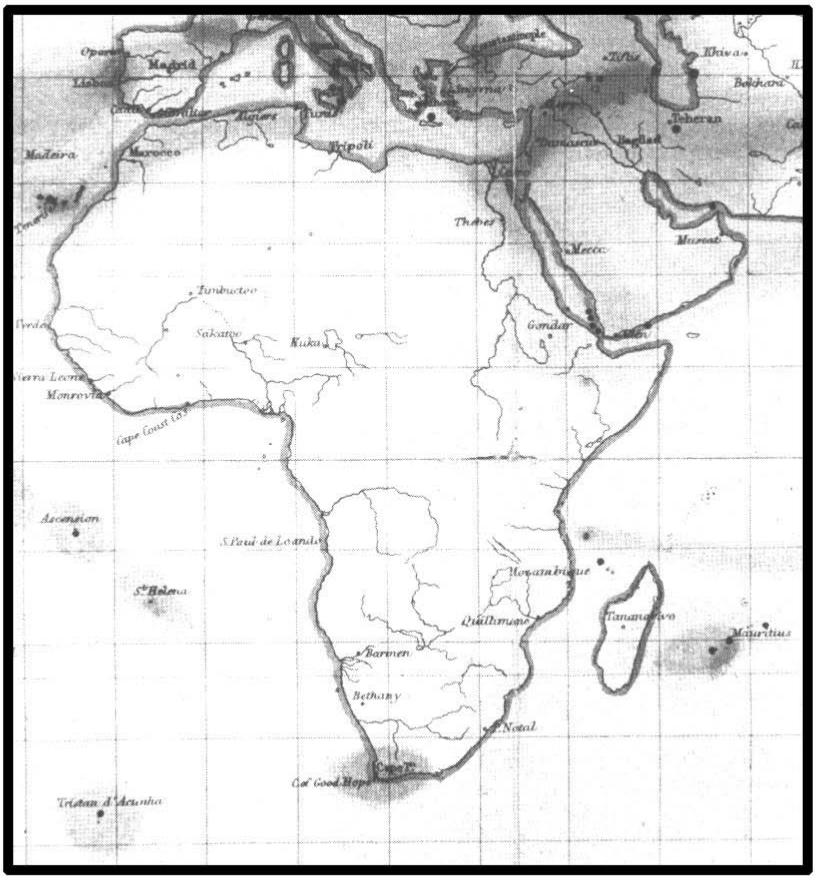
Figure 1. The oldest seismic hazard map, compiled by Mallett in 1853-1855, showing Cape Town as a known seismic zone (after ref. 12 , Fig. 1.3, p. 5). Note also areas of elevated earthquake activity in North Africa around Algiers, in Italy, around "Constantinople" (modern Istanbul, Turkey) and in the Levantine zone between Cairo, Jerusalem, and Aleppo, extending towards the Caspian Sea.

Figure 2. Broadband vertical component (BHZ) seismogram of the Matjhabeng mine (Welkom) earthquake recorded at a distance of 1.43° (159 km) by the Boshof station (BOSA – 28.6137°S 25.2559°E) operated under the Comprehensive Nuclear Test-ban Treaty. This magnitude 5.1 earthquake occurred at 22h19m38.2s (UT) on 22 April 1999 with an epicentre at 27.9021°S 26.6636°E, causing two deaths, substantial property damage, and R24 million mine production losses. The seismogram (start at ~22h19m) shows the impulsive P-wave arrival ("first shock') at 22h20m05s, followed by the S-wave ("second shock") at 22h20m25s. This coincides roughly with the arrival of the "Lg phase" and is followed by the larger amplitude "Rg phase" at 22h20m35s, which dies away over an interval of ~10 seconds. This seismogram is very similar to one that would be recorded at Cape Town due to an earthquake in the Ceres-Tulbagh area, about 150 km distant. It therefore illustrates the reason for the reported 25-30 second duration of the 1857 earthquake. (BOSA seismogram obtained by the on-line World-Wide Web "WILBER" facility of the Incorporated Research Institutes for Seismology (IRIS) Data Management Centre in Seattle, USA.)

Figure 3. Map of the Cape Town region showing the location of the Milnerton Fault, relative to other previously mapped faults and dolerite dykes (evidenced offshore by "sub-marine magnetic anomalies"; base-map adapted from ref. 7, Fig. 7). JB marks the area of maximum destruction at Jan Biesjes Kraal during the earthquake of 4^{th} December 1809.

Figure 4. Major tectonic features within and around the African continent include the Nubia (NB), Somalia (SM), Eurasian (EU), Arabian (AR), Indian (IN), Capricorn (CAP), Australian (AU) and Antarctic (AN) plates. The stippled areas indicate "wide plate boundary zones", notably the NB-SM boundary incorporating the geologically youthful East African Rift System (adapted from ref. 22, Figure 2). the Western and Eastern Cape provinces lie marginally on the NB plate. Compare the original (small inset on lower right) that includes Cape Town within the NB-SM boundary zone.

Figure 1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Marocco
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Teheran
Bagdad
Thebes
Mecca
Muscat
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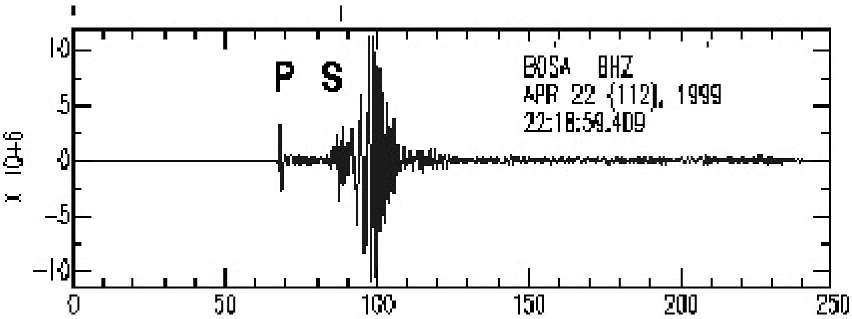
Sakatoo
Kuka
Gondar
Sierra Leone
Monrovia
Cape Coast Cas
Ascension
S. Paul de Loando
St Helena
Mosambique
Quilimane
Tananarivo
Mauritius
Barmen
Bethany
Natal
Cap of Good Hope
Tristan d'Acunha

Figure 2


P
S
BOSA BHZ
APR 22 (112), 1999
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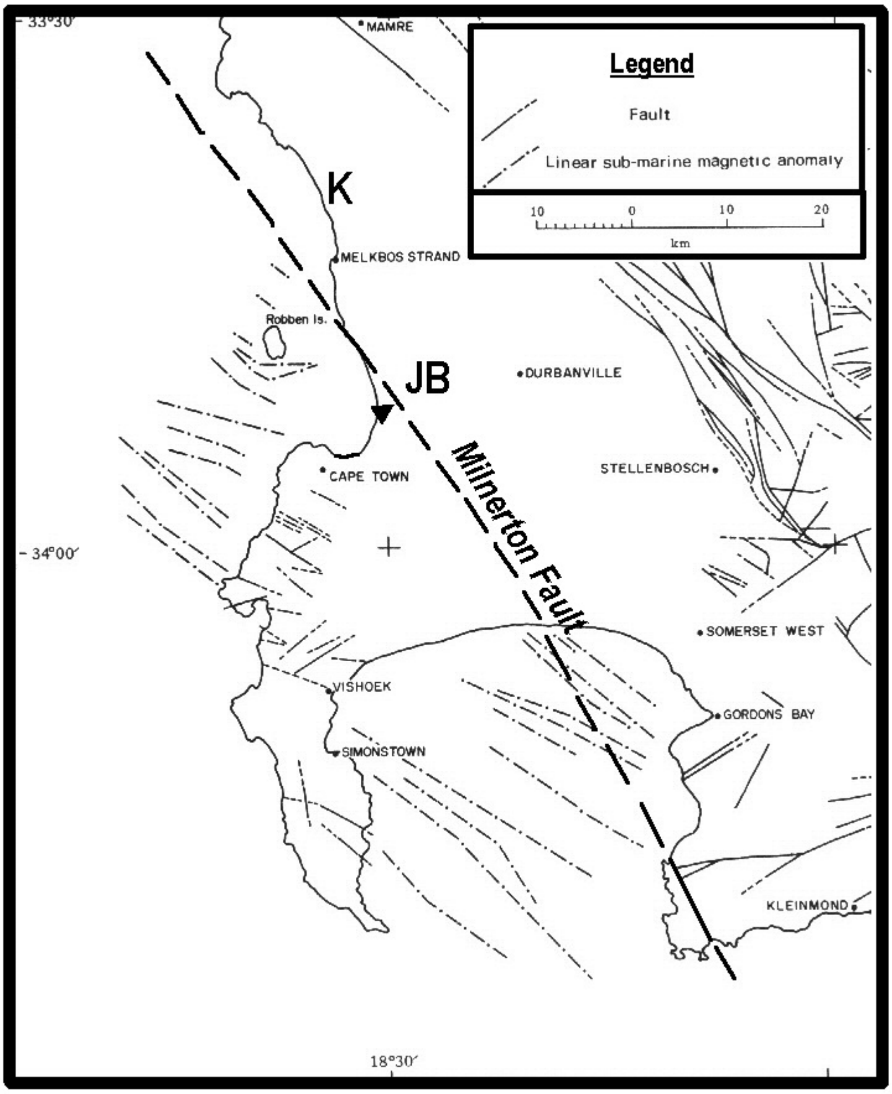
10
5
0
-5
-10
0
50
100
150
200
250

Figure 3



33°30′
MAMRE
Legend
Fault
Linear sub-marine magnetic anomaly
10
0
10
20
km
K
MELKBOS STRAND
Robben Is.
JB
DURBANVILLE
Milnerton Fault
CAPE TOWN
STELLENBOSCH
34°00′
SOMERSET WEST
VISHOEK
GORDONS BAY
SIMONSTOWN
KLEINMOND
18°30′

Figure 4