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The *b*-value as an earthquake precursor

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A systematic study of b-values in New Zealand has shown that within the vicinity of forthcoming large earthquakes there is initially an increase in b and then a return to normal. The Caracas and San Fernando earthquakes show the same phenomenon, which is related to that of seismic gaps.

IN the recurrence relation of Gutenberg and Richter¹, $\log N = a - bM$, the parameter *b* measures the relative numbers of small and large earthquakes. Values near unity are common. The value of *b* is usually calculated by the method of maximum likelihood (see ref. 2) whence

$$b = \frac{\log_{10} e}{\bar{M} - M_0}$$

\bar{M} is the mean magnitude of the sample and M_0 the minimum magnitude considered. The standard error in *b* is b/\sqrt{n} for a sample of *n* earthquakes² and the 95% confidence limits are twice this value.

Fiedler³ found that *b*-values increased before the Caracas earthquake of 1967. His estimates were of the 'extreme *b*-value' for each year, and they increased to 1.33 before dropping again before the earthquake. Wyss and Lee⁴ considered a sample of many more earthquakes, of much smaller magnitudes, in California. They calculated *b* using the maximum likelihood method and a 50-event window, and claim that it decreased both before and after main events. In their data the decrease before the main events took place over some hundreds of days. But there is also a suggestion of an increase in *b*, followed by a decrease just before the main event, the changes taking place over a few tens of days (for example at Danville, late 1971, where the magnitude of the main shock was 3.4).

Studies of aftershock sequences in New Zealand have also found that the *b*-value is not constant in time. In some cases Gibowicz⁵ found an increase after the main event, followed by a decrease before the next large shock. He also found large changes in *b* for large areas of the North Island⁶, as did Robinson⁷, who found an increase to a peak value of 1.75 in 1971, followed by a decrease.

This paper examines further evidence relevant to Fiedler's suggestion³ that a period of high *b*-values can occur before an earthquake.

High *b*-values in small regions

A systematic study of the temporal variation of *b*-values throughout New Zealand has now been made, using regions 2° in latitude by 2° in longitude, earthquakes of magnitude 4.0 and greater from 1955 to June 1979, focal depths less than 40 km, and a 50-event window which slides by 10 events. Smaller regions did not contain enough data for adequate resolution of the *b*-values. No attempt has been made to remove swarms and aftershocks from the data. Results for several of the regions are shown in Fig. 1, where the *b*-value is plotted at the time the last event entered the window. All five plots in Fig. 1 begin with low values of *b*, and this implies a lack of detection of small events before the mid 1960s when the New Zealand seismograph network was expanded to reduce the detection threshold to

Table 1 Total precursor times, from the onset of the increase in *b*-values to the occurrence of the earthquake

Earthquake	Magnitude	Precursor time
Tejon Pass, 1961	5.0	3.5 yr
Caracas, 1967	6.7	7 yr
Inangahua, 1968	6.8	6 yr
San Fernando, 1971	6.4	7 yr
Region E, 1971	5.9	3.2 yr
Region C, 1973	5.7	4 yr
Region A, 1977	6.0	7 yr
Pukaki, 1978	3.8	6 months
Pukaki, 1978	4.6	16 months

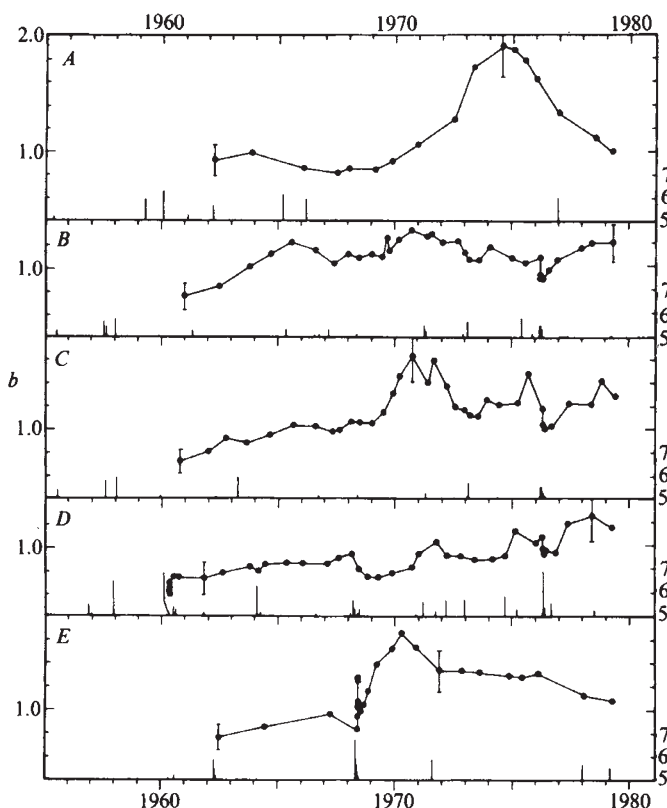


Fig. 1 The variation of parameter b from 1955 to 1979, in each of five regions of New Zealand. A location map is given in Fig. 2. Standard errors are proportional to b and are shown in a few cases, as are earthquakes of magnitude greater than 5. A 50-event window has been used, sliding by 10 events.

magnitude 4.0 throughout the country. Standard errors, proportional to the ordinate because of the uniform window length, are shown in several cases. Also shown are the earthquakes of magnitude > 5 in each area. A location map is shown in Fig. 2.

In region A the b -value rose to a peak of 1.9 in 1974 and then decreased. During the decrease there was an earthquake of magnitude 6.0. The high b -values were accompanied by a paucity of moderate earthquakes. During the period 1969–76, while the b -value rose to its peak then began to drop, there were no earthquakes over magnitude 5.0 in the region.

Figure 1B shows the b -value variation for another area, in the east of the North Island. Little variation is evident, although there was an earthquake of magnitude 5.9 in June 1975. Figure 1C plots a region in the north-east, where a high value of b (1.6) was followed by an earthquake of magnitude 5.7 in 1973 which occurred near the city of Napier. Figure 1D shows a similar plot for the Fiordland area, exhibiting very little variation in b in spite of the large earthquake in 1976. This point is taken up again later.

Figure 1E shows the Inangahua earthquake of 1968 (magnitude 6.8), and a marked increase in b which followed it. It is clear that high values of b , while they may be associated with imminent earthquakes, may also relate to previous activity. If Fig. 1E is any indication, however, the previous event should be easily identified, and in this case the period of high b -values could also be associated with the magnitude 5.9 event in 1971.

Figure 3 shows data obtained from the Lake Pukaki micro-earthquake network, situated in the South Island of New Zealand near 44°S, 170°E. This network of nine stations was installed in 1975 to monitor seismicity there during the raising of the lake level for hydroelectricity generation. b -Values have been calculated for magnitudes 1.5 and greater, using a 50-event window which slides by 10 events. In December 1978 an earthquake of magnitude 4.6 occurred close to the centre of the

network⁸. This event was preceded by a period of high b -values. There may also be another occurrence of the same phenomenon before the magnitude 3.8 shock of August 1978, superimposed on the larger trend.

Further evidence concerning whether or not periods of high b -value are followed by large earthquakes must be sought in other seismic regions, by systematic studies such as has been done in New Zealand. But the converse—whether or not large earthquakes are preceded by periods of high b -value—is examined in Fig. 4. The region 34–35°N, 118–119°W includes the San Fernando earthquake of 1971. Data selected from the Southern California catalogue⁹ are shown in Fig. 4A. The magnitude threshold is 2.5 and the window length is 20 events, sliding by five events. Decreasing the window length was necessary because of the small area chosen and the generally low level of seismicity, even at the magnitude 2.5 level, but, of course, the standard error increases. Two periods of high b -value are evident (approximately double the background level), one before the earthquakes of 1961 and 1963 in the Tejon Pass quadrangle, and the other before the San Fernando earthquake of 1971. The data set did not include the San Fernando earthquake itself.

Figure 4B shows a reexamination of the data for area e (see Figs 1 and 2). The window length has been reduced to 20 events, sliding by five events. The b -value increased to 2.2 before the Inangahua earthquake of 1968. This is an alternative expression of the precursory gap which Evison¹⁰ found for that earthquake. The area is of only moderate seismicity, and detection may not have been complete to magnitude 4.0 in the early 1960s. Both of these reasons demanded the short window. There is no clear decrease in b before the earthquake, but note that the final value of 2.2 at the beginning of 1968 represents an average back to 1963. There is clearly insufficient data to resolve any decrease which may have occurred before the major event. Extending the data sets to include the San Fernando and Inangahua earthquakes returns the b -value to its background level in each case.

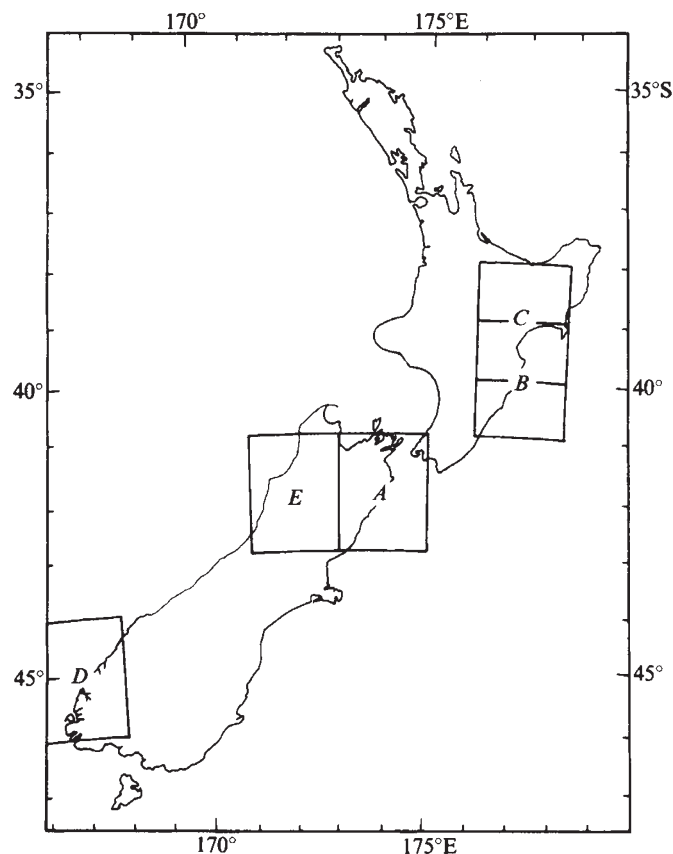


Fig. 2 Location map for the regions of Fig. 1.

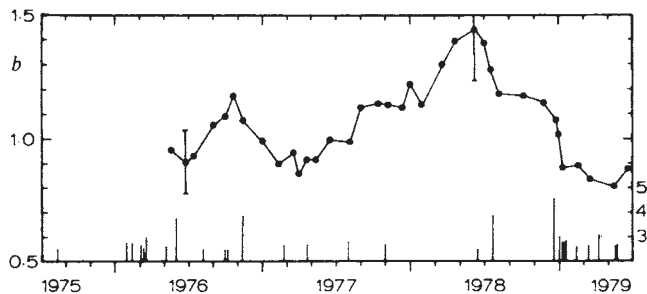


Fig. 3 b -Values for the Lake Pukaki seismic network. Magnitude threshold 1.5, window length 50 events, sliding by 10 events. Earthquakes of magnitude 3.5 and greater are also shown.

The Fiordland area (Fig. 1D) is very active, and if there are precursory changes in b for the large events shown, it will be necessary to decrease the search area to isolate them. Precursory changes for individual earthquakes, if they occur, are obscured by the high level of activity. The same problem is also likely to occur in Japan or any highly active area. It may be intensified in Fiordland where the source regions of earthquakes are generally small.

It is interesting to simulate these windowed b -value calculations using a synthetic data set with an exponential frequency distribution. The b -value so calculated does, of course, fluctuate. In fact the probability that the observed changes in b with real data occurred by chance is significant (if the earthquake population does actually have a random exponential distribution), but this is not the point. The proper question is: 'Are periods of high b -value followed by large earthquakes?'. The evidence presented here suggests that they are.

Note also that b -values have been calculated only as a statistical parameter of the small samples. No extrapolation to large samples is implied. The b -value is directly related to the mean magnitude, which may be a more useful parameter, but the terminology has been retained in favour of the well-known parameter b . A high b -value implies a low mean magnitude.

The b -value as an earthquake predictor

The evidence presented, that a period of high b -values is followed by a large event, is alternately expressed in the gap hypothesis. Mogi's¹¹ "seismic gap of the second kind", defined

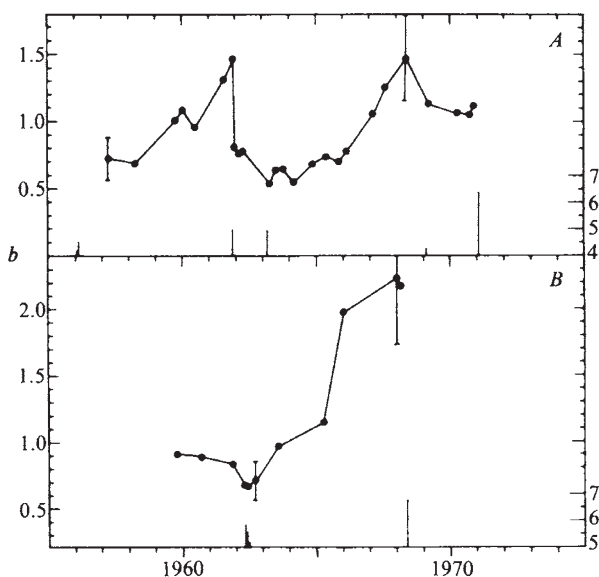


Fig. 4 b -Values for: A, the region of the San Fernando earthquake of 1971 (34–35°N, 118–119°W; $M \geq 2.5$) and B, the Inangahua earthquake of 1968 (41–43°S, 171–173°E; $M \geq 4.0$). Window length 20 events, sliding by 5 events. Earthquakes of magnitude greater than 4.0 (A) and 5.0 (B) are also shown.

as a region deficient in moderate earthquakes before the occurrence of a large earthquake, may find expression in a high b -value. Evison's¹² suggestion of a precursory swarm followed by a gap may also be accommodated by identifying the swarm with the initial low value of b .

The b -values in each frame of Fig. 1 are calculated for an area rather larger than the precursory gap area for any of the earthquakes. This is encouraging for a surveillance scheme, if the b -value does indeed prove to be a predictor, because a routine procedure to examine the whole country for changes in b -value need not use search areas coincident with the aseismic area related to the forthcoming shocks it is endeavouring to detect. Provided that the search areas overlap the precursory area, but are not too much larger than it, the anomaly in b -values will be detected. The maximum b -value reached is not very significant, because of the mixed population it represents. What is apparently important is the temporal behaviour.

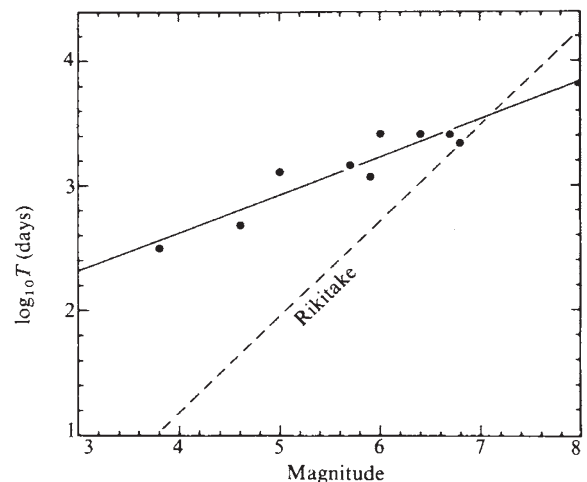


Fig. 5 Total precursor time T as a function of magnitude, for the earthquakes listed in Table 1.

Precursor time and magnitude

Total precursor times for the nine events identified are shown in Table 1, and in Fig. 5 as a function of magnitude, with the least squares regression:

$$\log T = 1.42 + 0.30M$$

For the Caracas event a magnitude of 6.7 has been used, as quoted by Rial¹³, although the ISC value of m_b was only 5.7. The regression is admittedly poor, and heavily dependent on the two Pukaki earthquakes of magnitude 3.8 and 4.6. But clearly the b -value does not fall into the class of phenomena which obey Rikitake's relationship¹⁴, also shown. The windowing technique can only reduce the observed precursor time, never increase it. This means that the ordinates plotted may be systematically small, except for the Caracas precursor which was determined from annual values. There seems to be no clear rule for the elapsed time from the b -value peak to the major earthquake, but this may be due to the windowing technique and the variety of seismicity levels in the data presented. The occurrence of foreshocks would tend to depress the b -value before a large event¹⁵, but this is a phenomenon on a much shorter time scale than that presented here.

Conclusions

The occurrence of a period of high b -values before a large earthquake has been observed in New Zealand, California and Venezuela. Only one case is known where it may have been associated with a previous event, the occasion when high b -values followed the Inangahua earthquake of 1968, but there was also a subsequent earthquake of magnitude 5.9 with which the high b -values could be associated. There may be a decrease

in *b* towards normal levels before the earthquake actually occurs, but it is difficult to resolve this in areas of low seismicity. The regression between magnitude and precursor time is poor, but the *b*-value clearly does not fall into the general class of phenomena which obey Rikitake's well known relationship.

I thank Drs E. G. C. Smith, R. Robinson and T. Hatherton for their helpful comments, and analysis staff at the Seismological

Observatory for painstakingly locating many thousands of small earthquakes. Dr Smith also performed the calculations on the synthetic data sets.

Note added in proof: Ma¹⁶ has also found evidence for high *b*-values before large earthquakes in China, including the Tangshan and Haicheng events.

Received 2 June; accepted 27 August 1980.

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Actin-containing matrix associated with the plasma membrane of murine tumour and lymphoid cells

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A detergent-insoluble matrix has been isolated from murine tumour cell and lymphocyte plasma membranes. The major components of this matrix include actin and four additional proteins not previously identified as cytoskeletal proteins. Labelling studies indicate that the matrix is located on the inner face of the plasma membrane. A cell-surface glycoprotein, 5'-nucleotidase, remains associated with the isolated matrix.

THE cytoplasmic face of the plasma membrane appears to be the meeting place for two sets of cellular structures intimately involved in determining the response of a cell to its environment. It is here that the transmembrane cell-surface proteins may interact with components of the cytoskeletal system. The red cell membrane has served as an extremely useful model for understanding many aspects of the plasma membrane of more complex cells¹, but whether the similarity of red cell membranes and the plasma membranes of nucleated cells extends to one of the most striking features of the red cell membrane, the 'membrane skeleton', has remained unclear. Recent studies have revealed that the red cell membrane is not composed simply of a lipid bilayer with individual proteins interacting with it. Instead, spectrin and a group of associated proteins form an extensive network at the cytoplasmic face of the bilayer and function as a membrane skeleton to stabilize the membrane. This skeletal network controls the shape and elasticity of the membrane^{2,3} and the distribution of transmembrane glycoproteins⁴ and intramembrane particles⁵. The network can be readily isolated by extracting membranes with the non-ionic detergent Triton X-100. Spectrin, the major skeletal protein, along with the other network proteins and some of the membrane lipids, remains insoluble⁶. The results of numerous recent studies have led to an increasingly clear picture of how these proteins are organized to form the skeletal network⁷.

Spectrin is present in all mammalian and avian red cells but is not found in other cell types and a membrane skeleton similar to the spectrin network has not been demonstrated in nucleated cells. These cells have extensive filamentous cytoskeletal networks within the cytoplasm^{1,8,9} and it has been proposed that there are associations between transmembrane surface proteins and components of this cytoskeletal network at the inner surface of the membrane^{8,10}. These interactions may be involved in such phenomena as capping of surface molecules on lymphocytes^{11,12}, control of cell motility¹³ and attachment to surfaces¹⁴. Some direct evidence for interactions between transmembrane

proteins and components of the cytoskeletal system has been presented^{15–17}. Whether such interactions, primarily implicated in dynamic processes such as receptor redistribution or cell motility, might also serve to stabilize the membrane is unclear. It is also unclear whether a distinct structure exists on the cytoplasmic face of the membrane, analogous to the red cell membrane skeleton. The results reported here demonstrate that a detergent-insoluble component can be isolated from the plasma membranes of murine tumour and lymphoid cells which may function as a membrane skeletal network. The network is apparently located on the inner surface of the membrane and has five major protein components. Only one of these proteins, actin, has previously been shown to be a component of cytoskeletal structures.

Plasma membrane isolation and Nonidet P-40 solubilization

Plasma membranes were isolated as described previously for P815 ascites cells¹⁸ with only minor modifications (see Fig. 1 legend). This procedure results in a 40–50-fold purification, as assessed by 5'-nucleotidase activity, and a yield of 40–60%. Co-purification of the cell-surface H-2 antigens with the plasma membrane fraction (ref. 18 and unpublished data) confirmed the results obtained by assaying 5'-nucleotidase. Membranes have been purified from P815, EL4, RDM-4 and CH1 murine tumour cells and normal murine spleen cells with essentially identical results. Examination of the purified membranes by electron microscopy shows them to be in the form of vesicles of relatively heterogeneous size, ~0.1–1.2 µm in diameter¹⁸. Small amounts of endoplasmic reticulum are also apparent, as indicated by the presence of some membrane vesicles with bound ribosomes. Based on yields obtained, the plasma membrane accounts for 1–3% of the total cell protein, in good agreement with values reported by others¹⁹.