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New Zealand Earth Strain Measurements

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New Zealand Earth strain measurements

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Three invar wire lever type Earth strain meters are being operated in geophysically interesting areas in New Zealand. The oldest has been operational since early 1970.

The main object of the work has been to detect possible strain changes occurring before an earthquake. None have been detected, the most likely earthquake to have produced an effect before hand having $M_B = 5.3$ and lying at $\Delta = 1°$ from the nearest strain meter. Strain steps accompanying earthquakes appear to be rather smaller than expected.

A great deal of information has been accumulated on strains induced by wind and rain at the most exposed site which is but 10 m below the top of a very exposed 300 m hill. Strain changes produced by several days' heavy rain can, at this site, be as much as 3×10^{-6}, and this indicates that great care must be taken in interpreting apparent changes in the length of a baseline measured by high precision surveying.

Introduction

The purpose of this paper is to describe instrumental developments and the results that have been obtained using invar wire lever type Earth strain meters of the type originally described by the author (Gerard 1971).

Three instruments are operating in geophysically interesting areas in New Zealand. The number of stations has been limited more by the availability of suitable tunnels than of actual instruments because these can be manufactured quite cheaply in the laboratory's workshops.

Local support for this project is given mainly because of the potential possibility that an earthquake prediction method may ultimately be developed. However, it is becoming very apparent that Wideman & Major's (1967) tentative assessment of the magnitude of Earth strain changes which might be expected before an earthquake is quite likely to be realized in practice. They opined that an instrument would need to be less than 25 km from the future epicentre of a magnitude 7 earthquake to detect a precursory strain change of 10^{-6}. This is a relatively large change in relation to instrumental sensitivity, yet no change at about the 10^{-9} level occurred before a local New Zealand earthquake of magnitude (M_B) 5.3 which had its epicentre about 100 km from the nearest strain meter (see figure 9).

Instrumentally, the extreme simplicity, reliability and resulting cheapness of the invar wire instrument compared with, say, a stabilized laser interferometer are making all the difference between having a small Earth strain project and having none at all.

Several years' experience with the invar wire instrument has indicated that its only disadvantage seems to be the slow secular expansion of invar. The author's wires are currently expanding at a rate of the order of 7×10^{-9} per day. This slows exponentially but shows no detectable discontinuities, and is in agreement with National Physical Laboratory results reported by Rolt (1929). Standard invar meter bars were expanding at about 10^{-8} per day a year after annealing and were still increasing at 10^{-9} per day 25 years later. Several instruments, each using wire from the same original sample should give useful comparisons of long-term differences in strain changes at different locations. However, it does seem that the absolute measurement of tectonic strain changes may require a stabilized laser interferometer, although monitoring the length of a sample of the wire with a laboratory interferometer could well turn out to be a practical means of achieving high long-term accuracy at a number of field stations equipped only with simple instruments. A simple system for monitoring a wire sample against a quartz rod is presently being developed. Meanwhile, the invar wire meter appears to be very successful for the measurement of strain changes having periods of up to several months.

The invar wire strain meter

Only a brief description of the instrument will be given here because it has been described in more detail in another paper (Gerard 1971). However, a new system for coping with long-term drift is described in more detail. Figure 1 is a drawing of the lever which provides a mechanical magnification (× 30) of the movement of the end of the wire relative to the earth. Also seen in the drawing is the linear variable differential transformer (l.v.d.t.) transducer. The main purpose of having mechanical magnification is to lessen the stability required of the l.v.d.t. and its associated 'carrier' amplifier rather than to provide extra amplification since, on its own, this is easy to obtain, but stability is not. The micrometer provides for the zero adjustment of the l.v.d.t. while there is also a coarse adjustment which directly alters the length of the wire. The lever is supported by, and rotates on two flat ligaments. The wire tension is essentially constant for the range of lever movement possible. An oil damper is used.

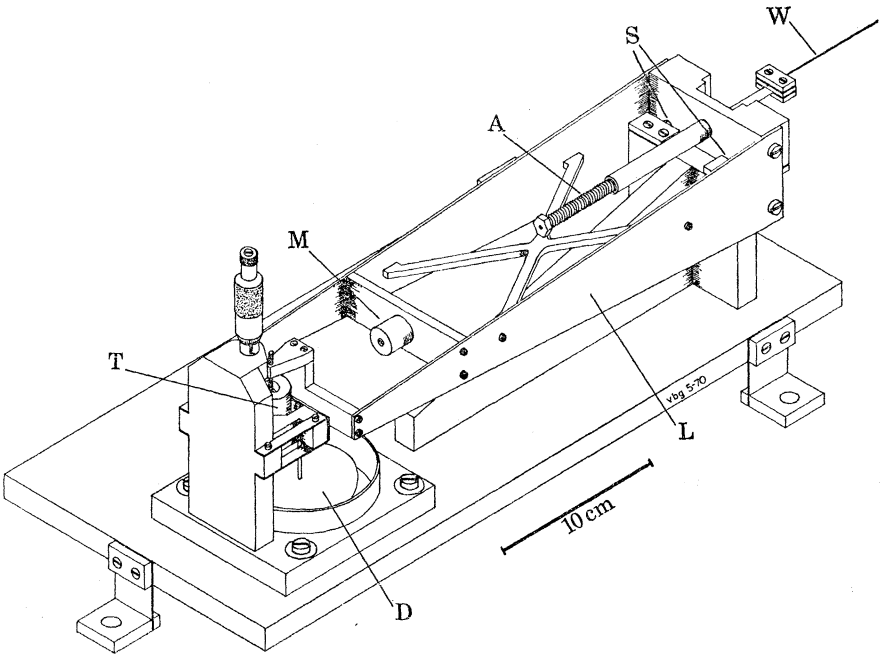

Figure 1. The magnifying lever, L, and transducer, T, which are used to magnify movements of the invar wire W. The wire length may be altered by the length adjuster, A. The mass, M, is selected to give the desired wire tension. The suspension ligaments are partly seen at S and an oil damper, D, is used.

The carrier amplifier has a maximum output (d.c.) of about 30 mV/μm movement of the l.v.d.t. core. This output is further amplified and may be filtered before being recorded. The main problem here is to ensure that the long-term drift, which is mainly due to the wire expansion, rock changes, or both, does not cause the recorder to run off scale after a few hours.

This may not be so important when it is possible to adjust the instrument manually, every day say, but at the author's Nelson station where only a monthly visit is financially possible other arrangements are necessary.

In the words of Rutherford, who was born only a few miles from this location: 'We have no money, so we must use our brains.'

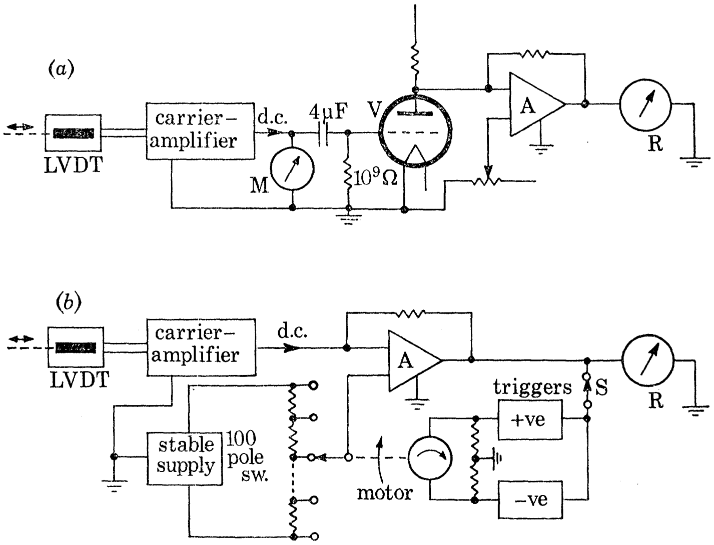

Figure 2. Outlines of solutions to the drift problem. In (*a*) the d.c. component is removed by a very long time constant r.c. filter. In (*b*) an automatic stepper keeps the recorder pen on the chart. See text for details.

Two schemes are in use and are shown in outline in figure 2. The most simple is that if figure 2(*a*) in which a high-pass r.c. filter with a time constant of 4000 s is used to remove the d.c. component but passes earth tide periods with an attenuation factor of 2 for a 12 h period. Long-term drift is noted from the meter, M, before the r.c. filter and of course a second recorder could be used here.

In figure 3, curve *a* shows the effective period response of this system, the flat response extending to infinity corresponds to recording the reading of meter M. The d.c. amplifier, which needs the high input impedance of the electrometer valve, V, has a gain of 20. The main disadvantage of this system is, of course, that full sensitivity is not retained for long periods, but a secondary disadvantage is that some selection of electrometer valves is really necessary to find one with a low contact potential drift rate.

Figure (2*b*) shows the outline circuit of a better method which retains the full sensitivity of the instrument to infinite period by automatically stepping the recorder pen across the chart as required. This, as can be seen from the figure, is done by means of two triggers which control a motor-driven stepping switch. The arrangement provides for 100 automatic steps and reduces the need for manual adjustments of the l.v.d.t. zero to about every 3 months at the Nelson station. In figure 3, curve *b* shows the response, the gain of the amplifier being also 20. Because a large earthquake would normally cause the recorder pen to repeatedly step from side to side, producing a very confused record, the triggering circuits have been arranged too perate only every hour by means of the switch S which is operated by the recorder chart drive. This also reduces the total current required by rendering the switching motor and its control circuits inoperative for all but 6 s every hour. Low-power consumption becomes of great importance when batteries are the only practical source and the power used by the complete strain meter,

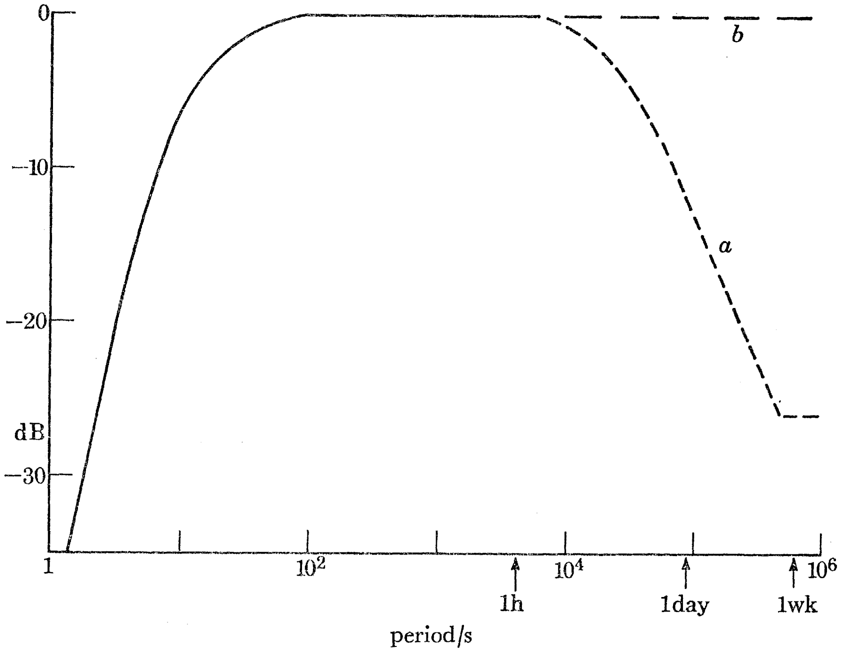

FIGURE 3. Period response of the strain meter, (*a*) with the system of figure 2*a*, (*b*) with that of figure 2*b*.

including recorder, is only 1.7 W for the figure 2(*b*) system, which is actually slightly less than that of figure 2(*a*).

An example of a typical record is shown in figure 4. It can be seen that minor loss of record can result if the pen goes off scale before switch *S* operates on the hour.

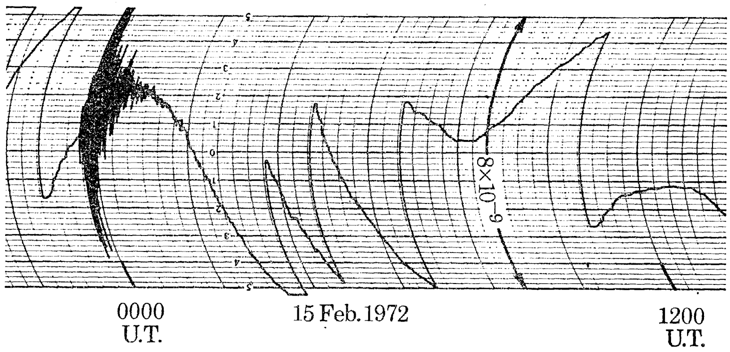

FIGURE 4. A record from an instrument using the system of figure 2*b*. Chart sensitivity is the maximum available. The earthquake having $M_B = 6.2$ was in the Solomon Islands region at a distance of 30° from the station.

INSTRUMENT STATIONS

Figure 5 shows the location of the instruments in use, together with historically destructive earthquakes and faults regarded by geologists as being active.

Because it is so disturbed by wind and rain the Wright's Hill site is nearly useless geophysically but has provided some interesting data on meteorologically induced strains, as discussed below. The instrument is in a well-sealed tunnel 10 m below the top of a very exposed 300 m hill not far from an exposed coast. It has been operating since early 1970.

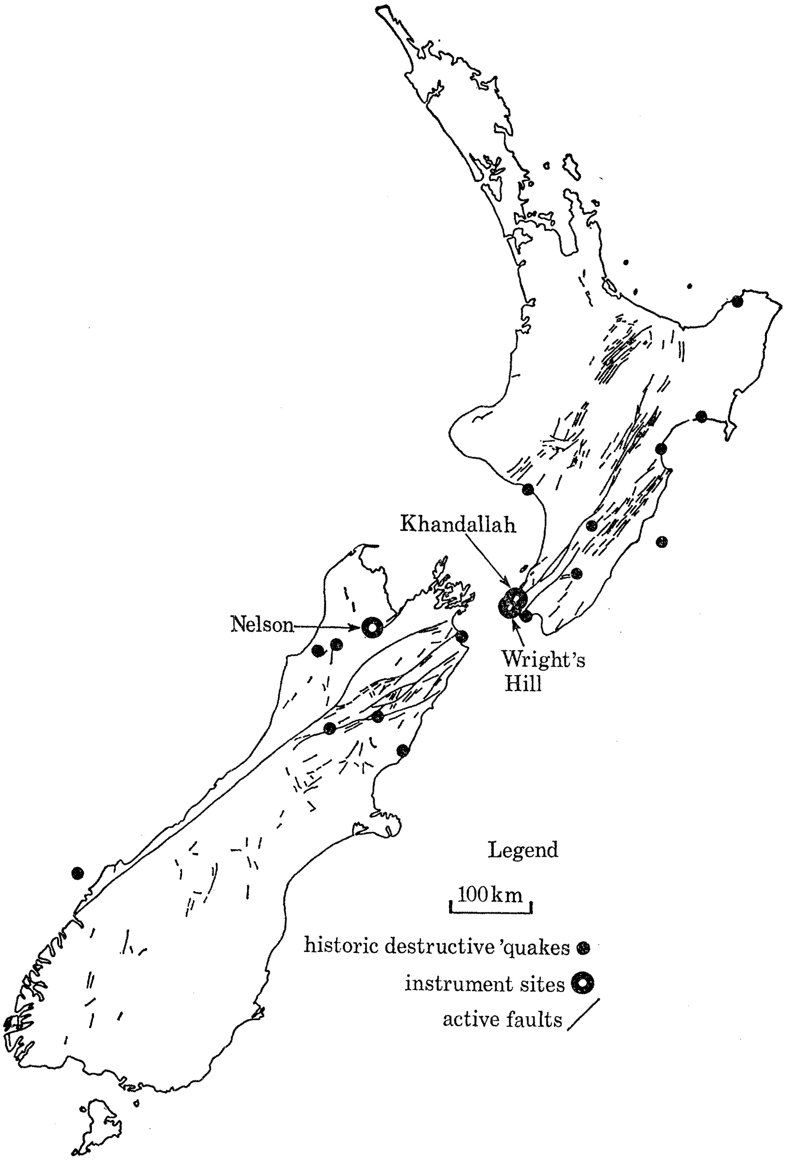

FIGURE 5. New Zealand showing instrument locations, historic (~ 130 years) destructive earthquakes, and geologically active faults (after Lensen).

The Nelson instrument is nearly a kilometre from the Earth's surface horizontally and about 150 m vertically. Apart from its lack of all services such as an access road and mains power it is very satisfactory and, being not far from the New Zealand Alpine fault, might be expected to show interesting long-term effects. It has been operating since mid-1971.

The third station, Khandallah is, like Wright's Hill, virtually in Wellington City but, being farther away from the Earth's surface, is proving to be nearly as good as Nelson. It has only been operational since January 1972.

METEOROLOGICAL STRAIN PHENOMENA

All the information in this section has been obtained from the Wright's Hill instrument, the others being too far from the Earth's surface to be materially effected by wind and rain.

Figure 6 shows that strong winds produce a noisy record, apparently shaking the hill bodily. No other mechanism can entirely explain the correlation because the instrument itself is almost hermetically sealed and the tunnels themselves are also well sealed against the ingress of draughts.

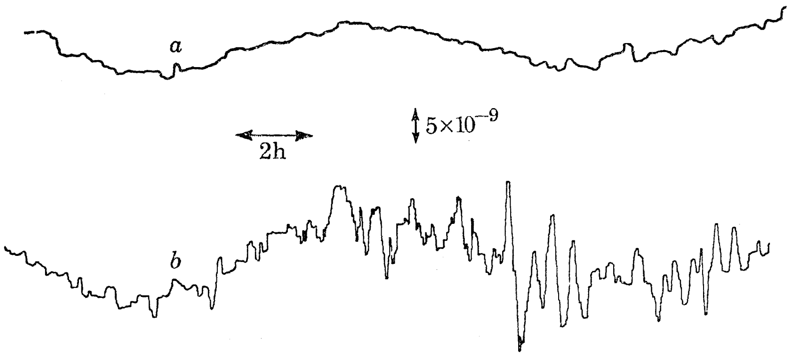

FIGURE 6. Earth strain at Wright's Hill, Wellington, New Zealand. Chart sensitivity is about one-fifth of the maximum available. (*a*) Meteorologically nearly calm conditions, wind gusting to 9 m s^{-1}. (*b*) Windy conditions, wind gusting to 30 m s^{-1}.

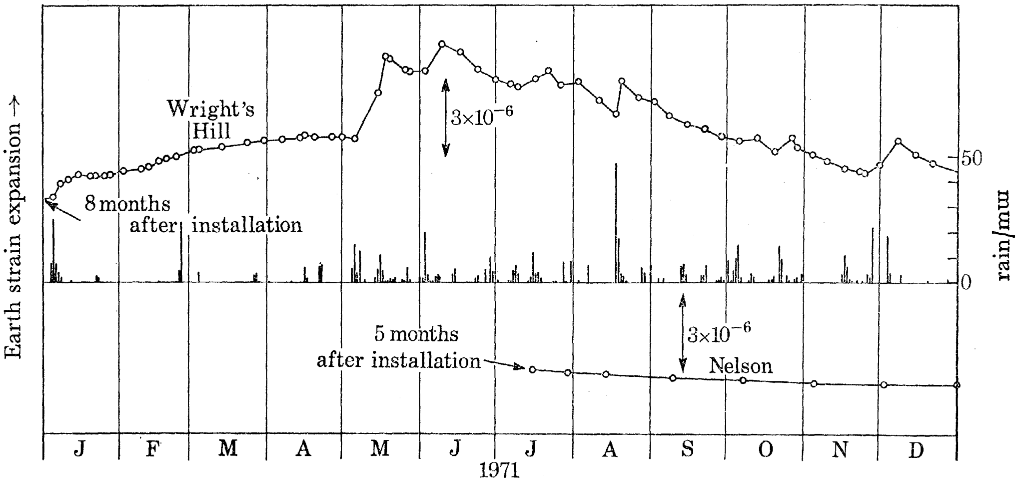

FIGURE 7. Long-term Earth strain at Wright's Hill and Nelson, New Zealand. A linear drift corresponding to a wire expansion of 8×10^{-9}/day has been removed from both strain curves. Note the correlation with rainfall in the case of Wright's Hill curve.

Figure 7 shows the 1971 long-term strain record from the Wright's Hill instrument, corrected for wire secular expansion, together with the daily rainfall at the nearest meteorological station which is about 3 km away. Also shown for comparison is the Nelson record for the period it was operating. The Wright's Hill record clearly shows a large number of changes of strain, corresponding to rock expansion, all of which occur after periods of rain. However, not all rainy days produce these changes and it is fairly evident that the strain change is a function of the amount

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of moisture absorbed by the soil and porous rock on the hill. Thus, a heavy downpour of short duration is likely to run off before much is absorbed. In summer a high evaporation rate may help. At the end of winter when the soil is more or less saturated more rain seems to be required to produce the same strain change. The most notable effect occurred in early May after a relatively very dry summer. It can be seen that at this time a few days of more or less continuous rain produced a 3×10^{-6} strain change over about 10 days. After the water absorption ceases and the hill begins to dry out the strain curve drifts back towards its old value. This occurs more with the onset of summer and, together with the annual temperature change within the hill, explains the pronounced annual component seen in figure 7.

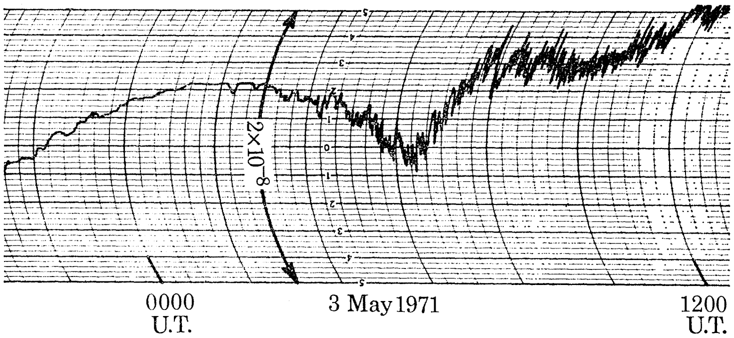


FIGURE 8. Wright's Hill record at the time of the onset of a sudden storm. The rain falling for several days afterwards produced the strain change occurring in early May shown in figure 7. As well as the shorter period wind disturbances similar to figure 6*b* there is also an abrupt change in the tidal curve.

The onset of a sudden storm is shown in figure 8, this being the beginning of the strain disturbance in early May 1971, just discussed. This storm was the beginning of a lasting change in the weather which had been unusually settled and dry for some months previously.

The changes of strain recorded are thought to be due to the strain field resulting from a wetting of the surface of the hill rather than an actual penetration of water to the depth of the instrument because, although the greywacke rock of the hill is fairly porous, it is thought that effective water penetration to a depth of 10 m is likely to take months rather than days. Somewhat similar effects have been described by Ward, Burland & Gallois (1968) in connexion with site evaluation for a proton accelerator.

The strain change on the hill's surface could perhaps be greater by an order of magnitude, or more, than that recorded at depth. The implications of this for high precision surveying are obvious, it being necessary to carefully evaluate any possible moisture factor before apparent changes in baseline lengths are attributed to, say, tectonic causes.

STRAIN STEPS ACCOMPANYING EARTHQUAKES

Very few examples of strain steps have been well recorded and their magnitudes have mostly been in the 10^{-10} range for distant earthquakes. They are rather smaller than to be expected from the paper of Wideman & Major (1967), although, however, those due to one or two nearby earthquakes do show rather better agreement. Because no fault parameters are available a comparison with the theoretical paper of Press (1965) has not been possible, although general agreement is not ruled out.

The fact that the strain steps are rather smaller than expected may perhaps be regarded as a good fault from an instrumental point of view because, in the past, large strain steps have sometimes been shown to be due to instrumental hysteresis.

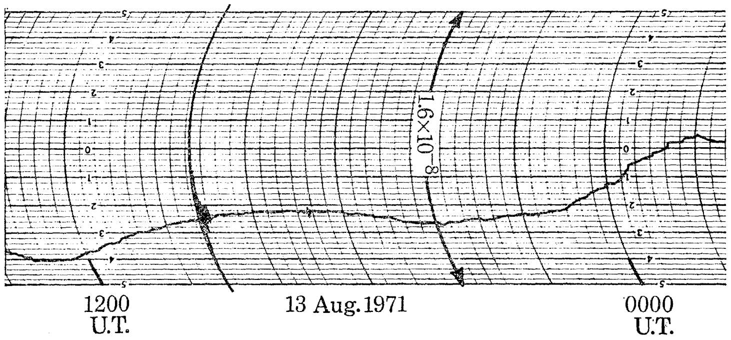


Figure 9. An earthquake of $M_B = 5.3$ about 1° distant from the Nelson station which was felt locally. No strain step is apparent and no precursory effects are evident either.

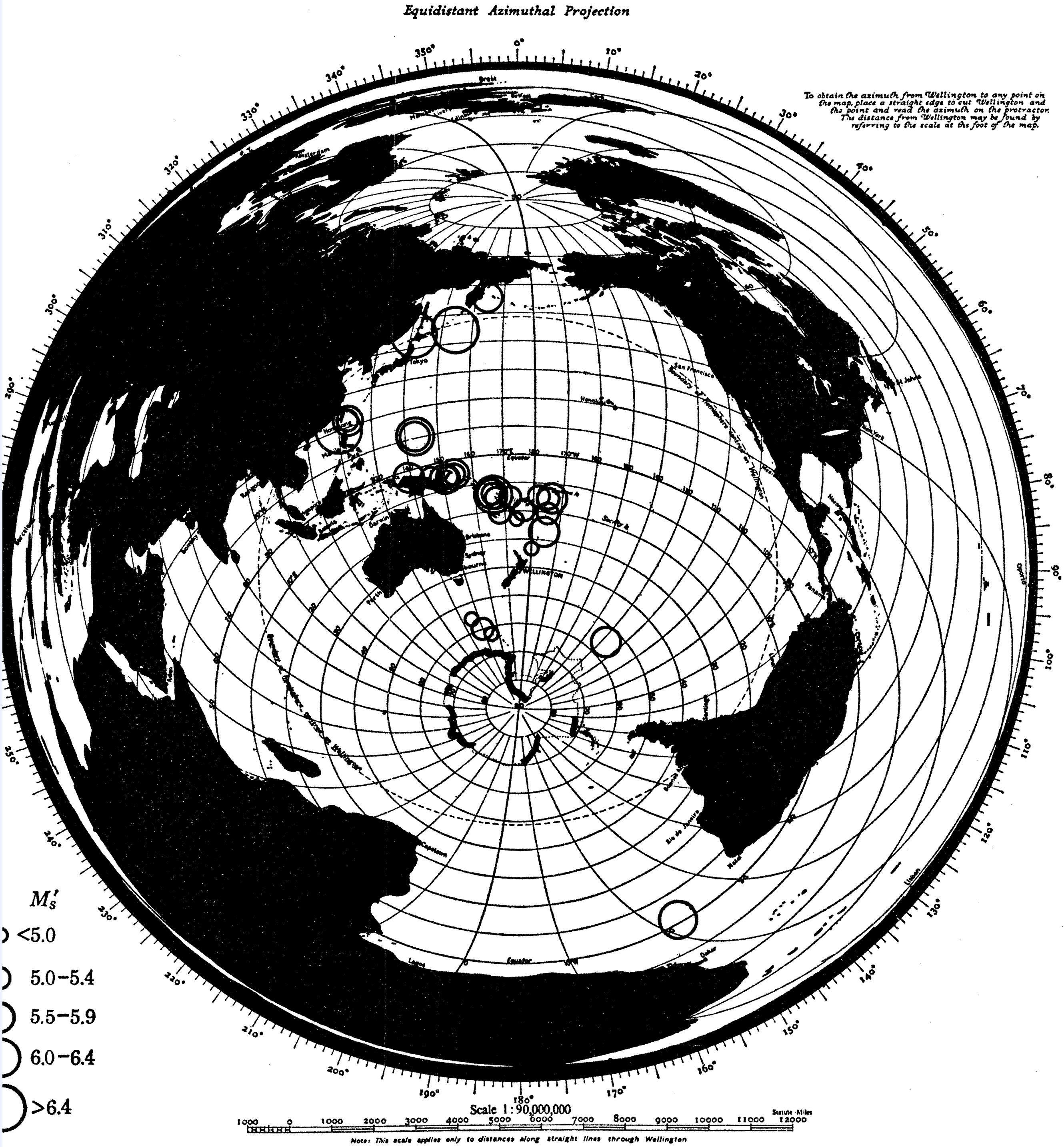
Figure 9 shows that the Nelson record of the earthquake mentioned in the introduction shows no apparent strain step, although, from Wideman & Major's (1967) work one of about 3×10^{-9} might have been expected. This was an earthquake felt locally and must have disturbed the instrument considerably so the absence of a step must be regarded as a good mark for it, as an instrument.

Surface wave detection of distant earthquakes

Because of the instrumental short period cut-off (figure 3) only surface waves are recorded from distant earthquakes. Benioff (1935) has shown that the directional response of a strain meter for longitudinal waves varies as $\cos^2\alpha$, where α is the angle between the rod (or wire) and the direction of propagation; and for transverse waves as $\cos\alpha\sin\alpha$. Thus the directional response for transverse waves has a null in the direction of the wires as well as at right angles to it. But, because surface waves are mixtures of both, a clear null is only be to expected at right angles to the wire. An attempt to locate such a null has so far failed for the Nelson instrument. In the case of Wright's Hill there have been two earthquakes, both with nearly the same epicentre which, while producing very strong responses on Nelson, produced none on Wright's Hill. At both times, by fortuitous good luck this instrument was undisturbed by wind. These nulls were 5° away from the geometrical direction. This is not surprising because Utsu (1971) has given a number of Japanese examples of island arc refraction of surface waves to give anomalous directions of arrival, and it is to be expected that similar effects would occur near New Zealand.

It is also well known (Gutenberg 1945) that surface wave-energy absorption can vary along different paths and give apparent M_S variations of up to a magnitude. Examples are also given in the same paper of azimuthal variations in the energy radiated by the source. These three effects obviously make the detection of directional nulls quite complicated.

A plot of earthquakes having epicentres above 70 km is shown for the Nelson instrument in figure 10 in which the parameter M_S' is the magnitude which would produce a maximum surface wave strain amplitude of 10^{-10} at the instrument. This is not far above the detectability limit for the Nelson instrument so M_S' can be regarded as an approximate indication of the



To obtain the azimuth from Wellington to any point on the map, place a straight edge to cut Wellington and the point and read the azimuth on the protractor. The distance from Wellington may be found by referring to the scale at the foot of the map.

Note: This scale applies only to distances along straight lines through Wellington

FIGURE 10. Sensitivity of the Nelson instrument to surface waves of distant earthquakes with epicentres above 70 km. Parameter M'_s is the magnitude which would produce a maximum surface wave strain amplitude of 10^{-10} at the instrument. To avoid confusion only some earthquakes are shown in regions where a number have occurred close together.

smallest earthquake likely to be recorded at the epicentre shown. For calculations, M_s values have been taken from N.O.A.A. bulletins. Any null is to be expected along or near to the geometrical azimuthal direction 175 to 355°, but, apart from the expected increase in M_s' with distance from New Zealand, no particular feature is noticeable except perhaps an indication of a higher than normal sensitivity to the south of New Zealand. However, this is only supported by five earthquakes and by the long path surface wave returns (not shown on figure 10) from two large earthquakes in the New Ireland region.

Because the Wright's Hill records are so often very disturbed by wind it has not seemed worth while to produce a similar plot although, as already mentioned, evidence of the instrumental null has been seen for two earthquakes.

It is perhaps worth noting here that the 'Cannikan' nuclear explosion in the Aleutian Islands produced no response on any instrument, which is consistent with its N.O.A.A. surface wave magnitude of 5.7, but if it had been a normal shallow earthquake having its body wave magnitude of 6.8 then it would have generated sufficient surface wave energy to have been well recorded.

CONCLUSIONS

Instrumentally speaking, the slow secular expansion of invar has not been found to be a great disadvantage. Good sites with a low noise level are generally hard to find and changes in surface moisture can be an added source of long period noise if the instrument is too close to the surface. This latter factor could be of importance in high precision surveying.

Strain steps recorded at the time of earthquakes seem to be smaller than expected from the analysis of Wideman & Major (1967).

Study of the prediction of earthquakes by detection of possible precursor strain changes before a large earthquake awaits the occurrence of nearby events of suitable magnitude, and it is recognized by the author that, given only the present small number of stations, the statistical probability of occurrence of suitable earthquakes in a reasonable time is very low. The only way to expect to get useful information from New Zealand, a country of small size and only moderate seismicity, would be to deploy something of the order of 100 instruments in all likely sites and expect to have to operate them for, say, 30 years before one might know if the method was ever going to enable predictions to be made. Tiltmeters, especially the bore-hole type, might be more practical from the viewpoint of obtaining suitable sites, but these instruments are very expensive. The situation has some similarities with that existing in meteorology of about a century ago when the use of the barometer for defining an isobaric map was well recognized, the collection of upper air information by balloon borne radio-sonde and satellite in the unforseeable future, and accurate weather forecasting not possible because of the lack of sufficient simultaneous information about the state of the atmosphere.

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