REPEAT MEASUREMENTS OF SEISMIC NOISE AT THE WAIOTAPU GEOTHERMAL AREA, NORTH ISLAND, NZ

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The amplitudes of seismic ground noise were remeasured at 66 sites in the Waiotapu and Reporoa geothermal areas in 1995 to determine whether amplitudes had changed since the first survey in 1970. In both 1995 and 1970 high levels of seismic noise occurred in two localities, one at Waiotapu and one at Reporoa. The elevated levels of seismic noise at most sites are thought to be caused by surface or near-surface geothermal activity. At seven sites in the Waiotapu area seismic noise levels were almost the same in 1995 as in 1970, indicating no change in the intensity of the source of the geothermal seismic noise. At most other sites the 1995 seismic noise levels were different to those measured in 1970, although at sites with high levels of seismic noise the differences were usually less than at sites with low levels of seismic noise.

INTRODUCTION

It has been observed that many geothermal areas exhibit a high level of seismic noise in the frequency range of 1 to 15 Hz (Liaw & McEvilly 1979, Iyer & Hitchcock 1976, Whiteford 1070,1975). The occurrence of high levels of seismic noise in geothermal regions was first noticed during seismic surveys reflection and refraction surveys being undertaken to explore the geothermal regions. These surveys were marred by both the high levels of background seismic noise and very high levels of attenuation of the seismic waves in the geothermal areas. The nature of this seismic noise was investigated in the 1970's to see if it was a characteristic of geothermal regions, and to determine whether measurement of the seismic noise could be used as a prospecting tool for delineating geothermal fields.

One of the earliest surveys of geothermal seismic noise was undertaken by Clacy (1968) northeast of Lake Taupo, (Fig 1). Clacy used recording techniques and instrumentation developed for observing volcanic tremor. He reported high amplitudes of seismic noise over geothermal reservoirs and claimed that the dominant frequency of the seismic noise could be related to the distance from the geothermal reservoir.

Subsequent more detailed surveys in the same region by Whiteford (1970) confirmed the high amplitudes in the vicinity of surface geothermal activity, but did not find any relationship between frequency and distance from the geothermal areas. After further investigations, Whiteford (1975) concluded that most of the seismic waves were surface waves, generated at a depth of approximately 100m by a mechanism such as a change of phase in the geothermal fluid. The surface waves did not appear to be attenuated abnormally, unlike the body waves associated with seismic surveys which travel at greater depths through the geothermal reservoir.

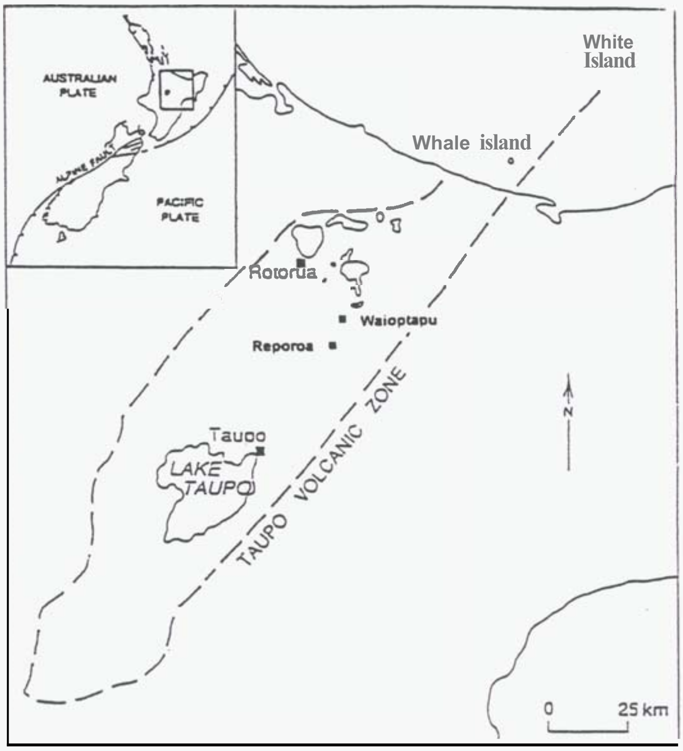

Fig. 1. Map showing the location of Lake Taupo and the Taupo Volcanic Zone, North Island of New Zealand.

Liaw & McEvilly (1978) studied seismic noise at the Grass Valley geothermal areas in Nevada, and also concluded that seismic waves associated with hot spring activity consisted of surface waves with no detectable body waves. The sources appeared to be shallow and localised. Iyer & Hitchcock (1976) observed elevated levels of seismic noise in Long Valley, California, which were related to the d a c e geothermal phenomena. Douze and Laster (1979) studied seismic noise in the Vicinity of the Roosevelt Hot Springs, Utah, but did not detect seismic waves that could be related to the geothermal reservoir.

Since the investigation of geothermal seismic noise in 1970 (Whiteford 1070,1975) no surveys of seismic noise in geothermal areas have been undertaken in New Zealand, and the only measurements of seismic noise have been local monitoring of Inferno Crater and Frying Pan Lake in the Waimangu Valley (Scott 1976,1991). In order to investigate whether any changes in the levels of seismic noise in the Waiotapu geothermal area had occurred since the last survey in 1970 a repeat survey was undertaken, and it is reported here. The aim was to repeat measurements at as many of the 1970 sites as possible and compare the levels of the seismic noise to test repeatability of such surveys. Because the 1970 recording instruments were no longer available, new instruments were constructed and used.

Recording Technique

Instruments

In 1970 the geothermal seismic noise was measured using several sets of portable instruments, each consisting of a Mk1 Willmore seismometer, an electronic amplifier, and an analogue recorder - either a tape recorder or chart recorder. In this (1995) survey the instrument set consisted of the seismometer, which, for consistency was the same model Willmore Mk1 as in 1970, together with an amplifier and a 12-bit analogue-to-digital (A/D) converter connected to a portable laptop PC. This digital recording system enabled the wavefonn of the seismic signal to be displayed on the laptop screen as it was being **measured.** Immediately after the measurement, the spectra of the signal was calculated and displayed on the laptop. These features enabled high quality seismic recordings to be obtained.

Seismometer

The Mk1 Willmore is an electrodynamic seismometer that gives a voltage output proportional to the velocity of ground movement, and is 0.7 critically damped. It is operated vertically, the Same as in the 1970 survey.

Electronic Amplifier

A conventional analogue amplifier constructed from low-noise low-power operational amplifiers provided voltage gains which could be switched between 100 and 6400 times.

A/D Converter and Laptop Computer

The 12-bit A/D converter, a Pico ADC-100, was plugged directly into the parallel port of the laptop computer and obtained its power fiom the parallel port. The laptop was a conventional IBM-compatible computer powered from a separate lead acid car battery. Although the laptop had internal Ni-cad batteries, these lasted only an hour of two of continuous use. The lead-acid battery ran the laptop for several days. Software was written in Turbo Pascal to control the A/D converter, make A/D readings at a rate of 50 Hz and display the waveform on the screen, calculate and display the spectra, calculate waveform average, and save the data to disk.

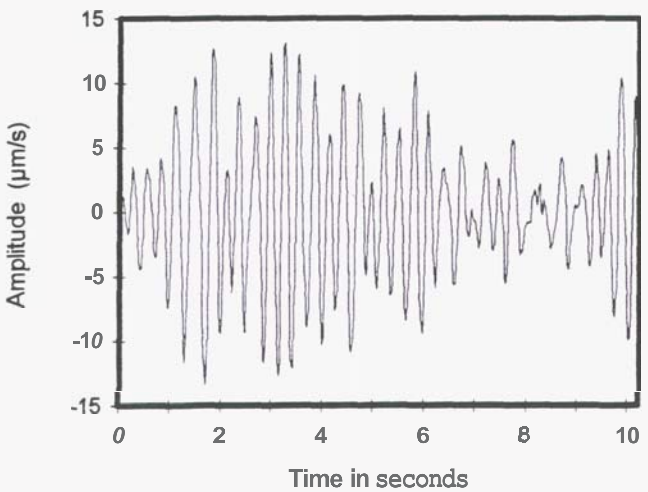

Fig. 2. A typical waveform of geothermal seismic noise, as displayed by the digital recording system.

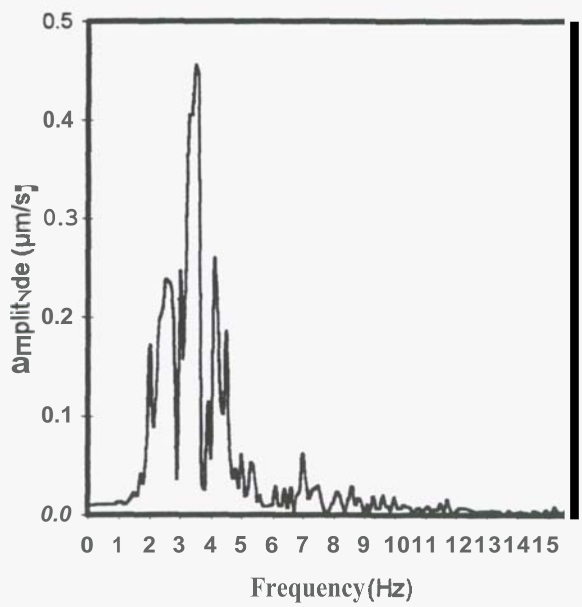

Fig. 3. A typical spectrum of geothermal seismic noise, as displayed by the digital recording system.

Field Procedure

Sites were chosen to be in the same location as the sites occupied in 1970. At some sites the relocation was estimated to be better than 10m, because of identifying features such as a nearby road intersection, road bend, or a topographic feature. At other sites, relocation was from map coordinates and was estimated to be within 200m. At each site, a small concrete slab was placed firmly on the ground and the seismometer placed on top of the slab. This ensured good coupling between the seismometer and the ground. Care was taken to ensure that the slab was stable with no tendency to wobble. If necessary, the ground surface was levelled with a spade to ensure good contact. Several measurements were then made, each 10 seconds long. The mean seismic noise amplitudes were noted, and the waveforms, and spectra were examined. If in successive measurements these were approximately the same , then no further measurements were made. Otherwise, measurements were repeated until similar. amplitudes, waveforms, and spectra were obtained. The cause of differences between measurements was usually local seismic noise, such as vehicle traffic or wind gusts. Vehicle traffic could easily be identified in the displayed waveform. Typical waveforms and spectra of geothermal seismic noise are shown in Figs 2 and 3. This measurement method, in which recordings of seismic ground velocity were made for periods of 10 seconds, was the same as that used for about one quarter of the sites measured in 1970. The other method used in 1970 was to record at a site for several days, in order to measure diurnal variations. In 1970 it was found that diurnal variations were significant in areas away from the geothermal activity where natural seismic noise levels were low. The diurnal variation was at a maximum during the day because of man-made effects (eg. traffic, machinery) and wind. The method of recording for a periods of 10 seconds and checking far consistency was considered to be suitable for measuring the levels of geothermal seismic noise, as the amplitudes of diurnal variations were generally much smaller than geothermal seismic noise. However, in areas where there was little or no geothermal seismic noise, the 10-second measurement would sample only a single point on the diurnal curve. Most of the measurements for this survey were made during the day, when the maximum normally *occurs,* and so the measurement would indicate a level of seismic noise that is high on the diurnal cycle.

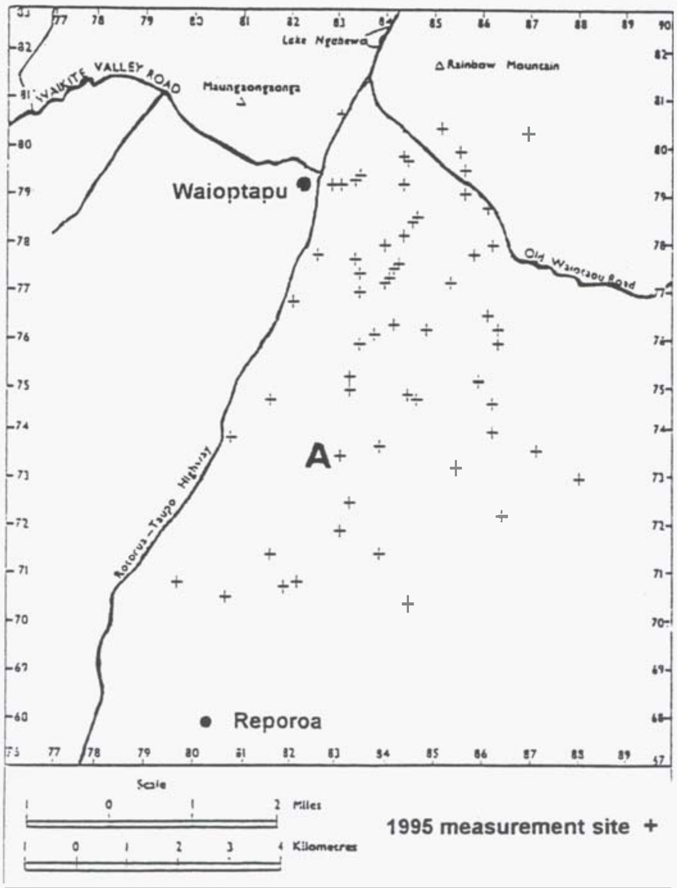

Fig. 4. Map showing the location of the measurement sites in the Waiotapu area; all were repeats of 1970 measurements.

RESULTS

A total of 66 of the 1970 sites were repeated. The locations of these are shown in Fig 4. The levels of seismic ground noise for these 66 sites varied over more than an order of magnitude, the highest level being 6 µm/s and the lowest being 0.4 µm/s. The mean of the measurements was 1.42 µm/s and the standard deviation 1.26 µm/s, while the median value was 0.86 µm/s.

The sites where seismic noise was greater than 1.0 µm/s are shown shaded in Fig 5. There are two areas encompassed by seismic noise levels greater than 1.0 µm/s. The northern area encompasses most of the surface geothermal activity in the Waiotapu area, and in the southern area there is surface geothermal activity associated with the Reporoa geothermal area (Bibby et al 1994).

DISCUSSION

The two areas of elevated seismic noise delineated by the 1970 survey are shown in Fig 6. It can be seen from Figs 5 and 6 that the Waiotapu area of elevated seismic noise levels outlined by this (1995) survey roughly coincides with the area outlined in 1970. The Reporoa high noise areas as outlined in Figs 5 and 6, however, differ between surveys, the 1995 area being larger. In the 1970 survey there are 3 sites to the northwest of Reporoa which had high noise levels but were not included in the shaded area, as there was no evidence for a geothermal origin of the seismic noise there. If these three 1970 sites are included, then the areas of elevated seismic noise in the Reporoa area is similar for both 1970 and 1995 surveys.

It was concluded in the 1970 study that the seismic noise in the high noise zone was produced by geothermal sources associated with nearby d a c e or near-surface geothermal activity (Whiteford 1970). This was verified in later studies of the location of the source of the seismic noise (Whiteford 1975). It is most likely that the elevated levels of seismic

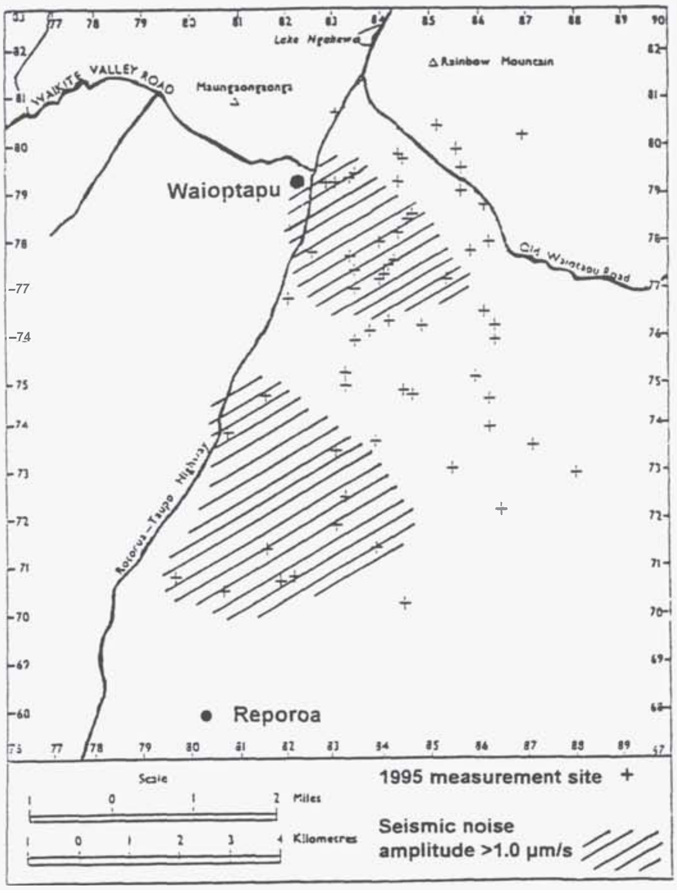

Fig. 5. Map showing the two areas of elevated seismic noise outlined by the 1995 seismic noise survey.

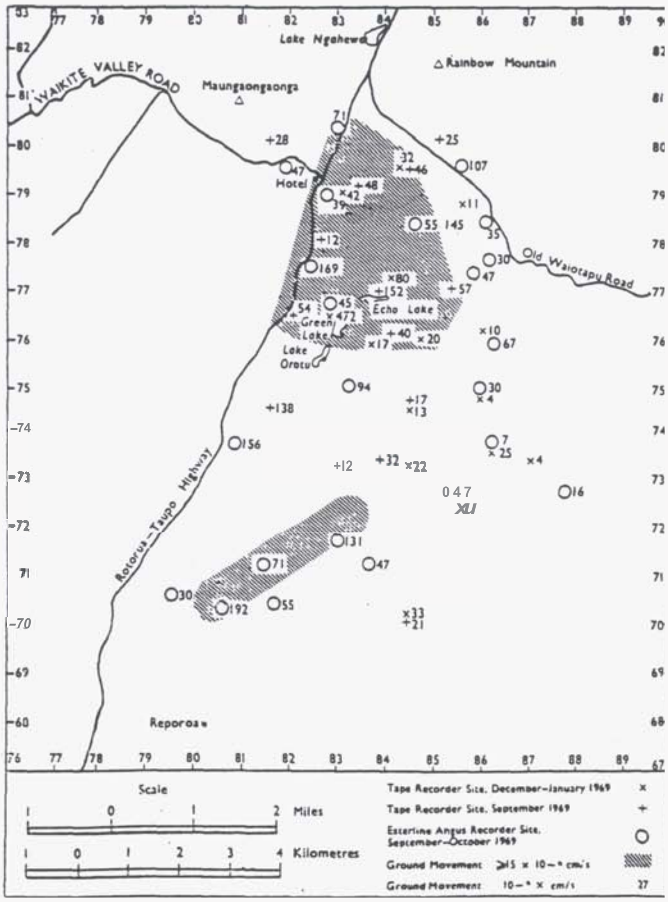

Fig 6 Map showing the two areas of elevated seismic noise outlined by the 1970 seismic noise survey.

noise in the northern high-noise area measured in this survey are of geothermal origin, as surface geothermal activity occurs near these sites.

The source of seismic noise is not so clearly established for the area of high levels of seismic noise in the southern (Reporoa) area, as there are some sites which do not have any surface geothermal activity nearby, eg site A (Fig 4) and the two sites to the northwest of site A. Non-geothermal seismic noise sources may cause the high seismic noise levels at these sites.

If non-geothermal sources of seismic noise cause high seismic noise levels they are most likely to exhibit a diurnal variation. To check for diurnal variation at site A (Fig 4), measurements were made in the middle of the day, and then at night. The influence of man-made and other noise is usually at a minimum at night and the repeat measurement could be expected to indicate the size of the diurnal variation. There was no difference between the two measurements indicating no diurnal variation, and hence the source of seismic noise appears to be a steady one, and may be of geothermal origin despite there being no surface geothermal activity nearby.

To examine the repeatability of the seismic noise, the amplitudes measured in 1970 were plotted against the values remeasured in 1995. If the remeasured amplitudes are identical to the original, then the plotted points will lie along a line of gradient 1.0. A systematic difference would give a gradient different to 1.0. Variability would appear as scattered points.

A plot of all repeated measurements is shown in Fig 7. A few of the points form a linear trend with a gradient of about 1.0, but most of the sites are scattered above this linear trend.

To examine the sites with levels of high seismic noise (>1.0 µm/s), the sites measured at Waiotapu have been plotted in Fig 8, and at Reporoa in Fig 9. In both figures there is less scatter than for the levels of seismic noise <1.0 µm/s (Fig 7).

The sites at Waiotapu for which the remeasured site was thought to be within 10m of the 1970 site are plotted in Fig 10. There are seven sites. Their values show a consistent linear trend, which indicates good repeatability. At these sites the seismic noise levels are almost unchanged between the 1970 and 1995 survey. This in turn indicates that no change occurred in the intensity of the geothermal source of the waves between 1970 and 1995.

The ratios of the seismic noise amplitudes measured at the same sites for the two surveys were calculated. The means and standard deviations of the ratios are shown in Table 1 for all sites, for sites with amplitudes > 1.0 µm/s at Reporoa,

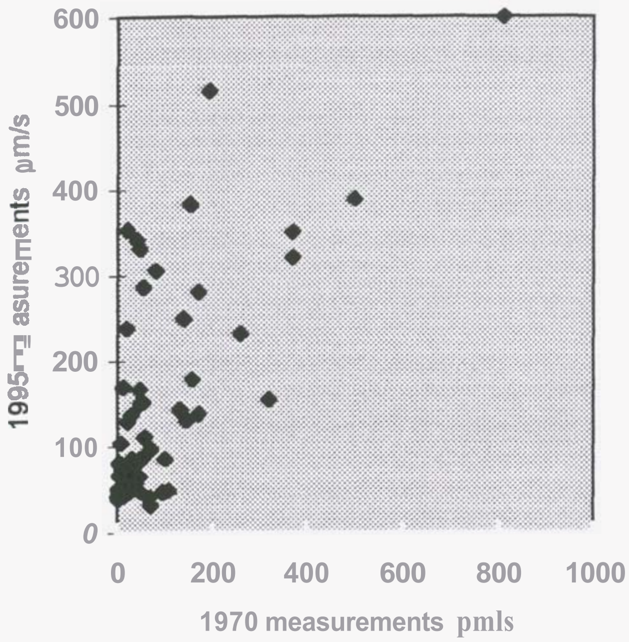

Fig 7 Graph of seismic noise amplitudes measured in 1970 at all sites plotted against the seismic noise amplitudes from sites remeasured in **1995,** *each point represents one site*

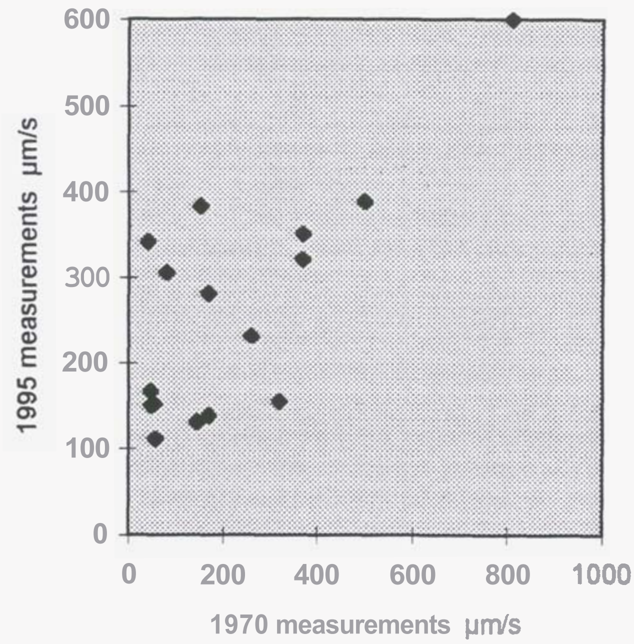

Fig 9 Graph of seismic noise amplitudes measured in 1970 at Waiotapu sites plotted against the seismic noise amplitudes from sites remeasured in **1995,** *each point represents one site*

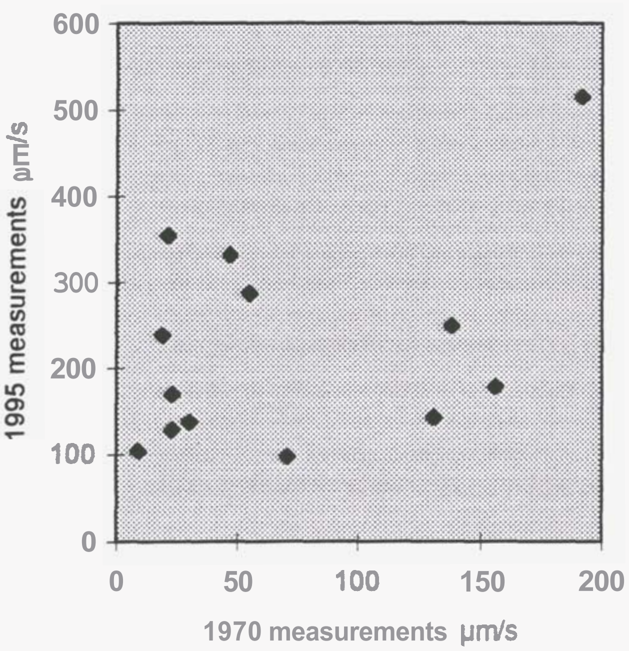

Fig **8** *Graph of seismic noise amplitudes measured in 1970 at Reporoa sites plotted against the seismic noise amplitudes from sites remeasured in* **1995,** *each point represents one site*

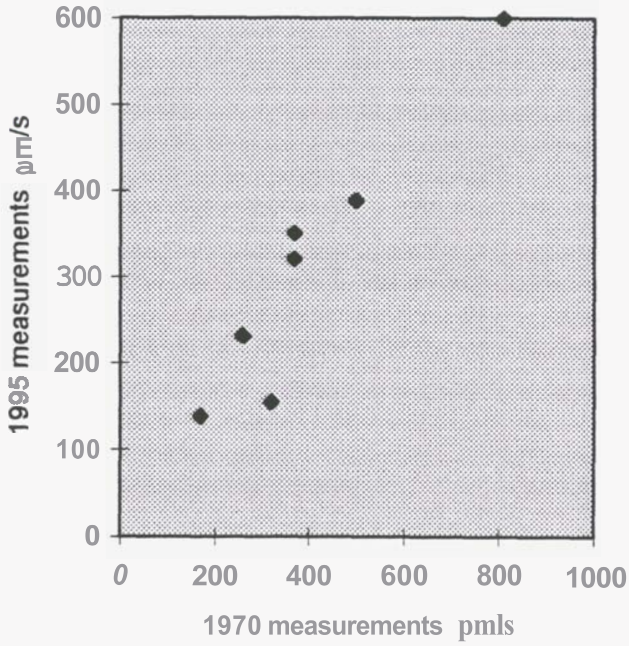

Fig 10 Graph of seismic noise amplitudes measured in 1970 at seven Waiotapu sites which could be accurately relocared in **1995** *plotted against the seismic noise amplitudes from sites remeasured in* **1995,** *each pint represents one site*

Waiotapu, and the seven Waiotapu sites which could be accurately relocated. The ratios for Reporoa sites with high seismic noise levels have large variability whereas the ratios for Waiotapu with high noise levels have moderate variability, and the seven Waiotapu sites which could be accurately located have low variability.

Table 1. Ratios of 1995 and 1970 seismic noise amplitudes.

	All sites	Reporoa >1.0μm/s	Waiotapu >1.0 μm/s	Waiotapu seven
Number	66	12	13	7
Mean	5.3	6.6	1.5	0.8
Std dev	5.9	5.2	1.0	0.1

The higher variability's between the present (1995) and 1970 surveys in the Reporoa area *can* be attributed to two factors. Firstly, the areas of elevated seismic noise defined by the 1970 survey were obtained from both shortduration and longduration (several-day) measurements, whereas in the 1995 *survey* only short-term measurements were used. The levels obtained fiom short-term measurements made during the day are likely to have a component of noise from the non-geothermal sources which cause diurnal variations, such as wind, or traffic and other man-made noise. The levels obtained in the 1970 *survey* fiom the longduration recordings were selected from the record at a time when the diurnal noise was at a minimum.

The second reason for this difference is *the* possibility that resonant effects may *occur* in Reporoa. Resonances will amplify seismic noise amplitudes, and hence amplify the variability. The nature of the land in the south is different from that in the north. It is open farmland with roads where man-made noise is generated. It lies in a relatively flat basin, which is part of the Reporoa Caldera and seismic waves may be amplified or exhibit resonance effects in *this* basin. In contrast the area in the north is mostly forest and consequently has few sources of man-made seismic noise. It is also unlikely to exhibit resonance effects because much of the area consists of low hills.

CONCLUSIONS

All repeated seismic noise measurements have uncertainties introduced due to the measuring techniques and instruments, the accuracy of relocating the site, the effect of diurnal variation of the seismic noise, the effect of ground or basin resonances, and the change in local noise sources. The effects are more pronounced in some areas than in others, and account for the variabilities observed between the 1970 and 1995 surveys. To reduce the effect of these uncertainties, long term recordings should be made using modem instruments in areas which may have low seismic noise levels or where resonances are likely.

The seismic noise amplitudes measured at 7 sites in the Waiotapu area were the same in 1995 as in 1970, indicating no change in the intensity of the geothermal source of the waves there. This area would be suitable for future studies of sources of geothermally induced seismic noise and in particular to develop techniques to monitor changes in subsurface fluid conditions induced by exploitation.. Such studies should extend the instrumentation to the use of beamed arrays.

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