LIQUEFACATION IN THE BULLER REGION IN THE 1929 AND 1968 EARTHQUAKES

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SUMMARY

This article describes the results of a search for sites of liquefaction in the 1929 M=7.6 Murchison and the 1968, M=7.1 Inangahua earthquakes in the Buller region of New Zealand. Evidence of liquefaction was found for nine sites in each earthquake; two sites were common to both events. Widespread ejection of sand occurred in the epicentral regions of both earthquakes. Liquefaction was more sporadic at larger epicentral distances, except in the North Beach area of Westport, the most distant 1968 site, where sand boils occurred over several hectares, together with the toppling of utility poles and some lateral mass movement. This area corresponded to the very young beach sands deposited since extension of the Westport harbour breakwaters towards the end of last century. Liquefaction was much less common in the river-lain sands in the same vicinity.

INTRODUCTION

A general study of historical cases of seismic liquefaction in New Zealand (Fairless, 1984; Fairless and Berrill, 1984) suggests that liquefaction has been common in large New Zealand earthquakes, and that it occurred quite widely in the 1968, M = 7.1 Inangahua earthquake. Prompted by the number of cases found in the literature by Fairless, a more intensive search was mounted for occurrences of liquefaction in the Buller region, the scene of the 1968 earthquake. Several new cases were found, together with additional information about previously known ones. As well, a number of cases from the 1929, M = 7.6 Murchison earthquake were discovered, some sites having liquefied in both earthquakes. Further, two sites near Westport possibly liquefied during the 1962 Westport earthquake sequence (Adams and Le Fort, 1963) but we wish to obtain corroboration of this before publishing details.

The aim of this article is to report the evidence of past liquefaction found in the Buller region and to pin-point sites for further investigation, and for inspection following future earthquakes.

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Sources of information include reports in the literature and press interviews with eyewitnesses and aerial photographs taken a few days after the Inangahua earthquake. Even in 1968, sand liquefaction did not attract the interest that it does today and most references to liquefaction in the literature are cursory, with few details or specific locations given. For 1929 no mention of liquefaction effects such as sand ejection or movement of near-flat slopes could be found in the technical literature.

Figure 1 shows isoseismal patterns for the earthquakes. Both were shallow focus events with surface faulting, predominantly in a thrust mode. Brief seismological descriptions of the earthquakes are given in the appendix and further geological and seismological references may be found from the bibliography. It is of interest to note that most of the Inangahua aftershocks lie within the MM IX isoseismal, indicating this was the region of rupture, with rupture propagating southwestwards from a northern hypocentre.

SITES OF LIQUEFACTION

General Remarks

Figure 2 shows the sites of liquefaction that have been positively identified. These sites are listed in Table 1 together with epicentral distances and notes giving the type of evidence found. All sites shown are on level or near level ground.

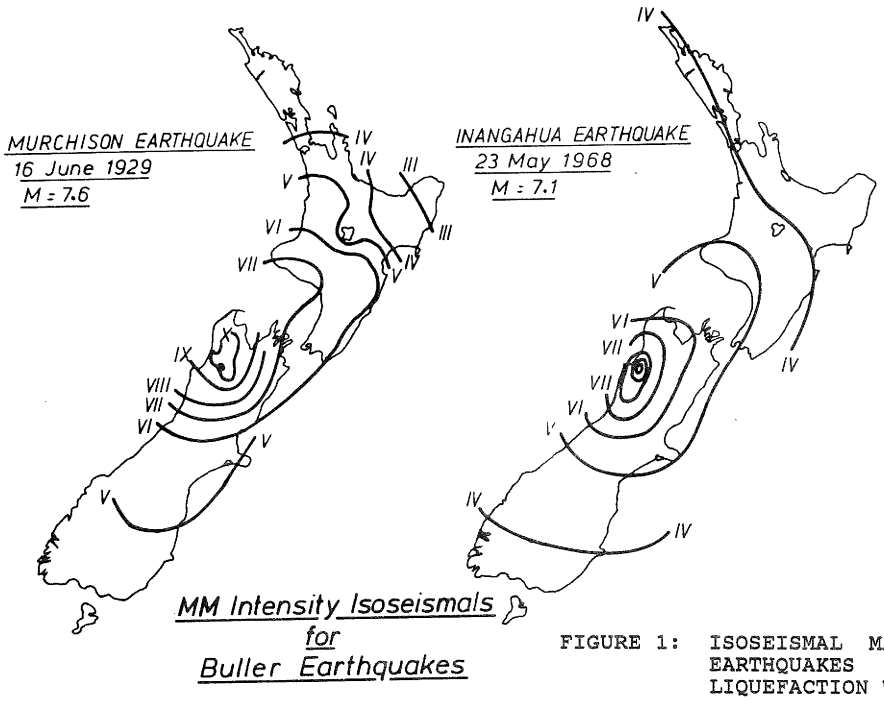

FIGURE 1: ISOSEISMAL MAPS FOR THE TWO EARTHQUAKES IN WHICH LIQUEFACTION WAS IDENTIFIED.

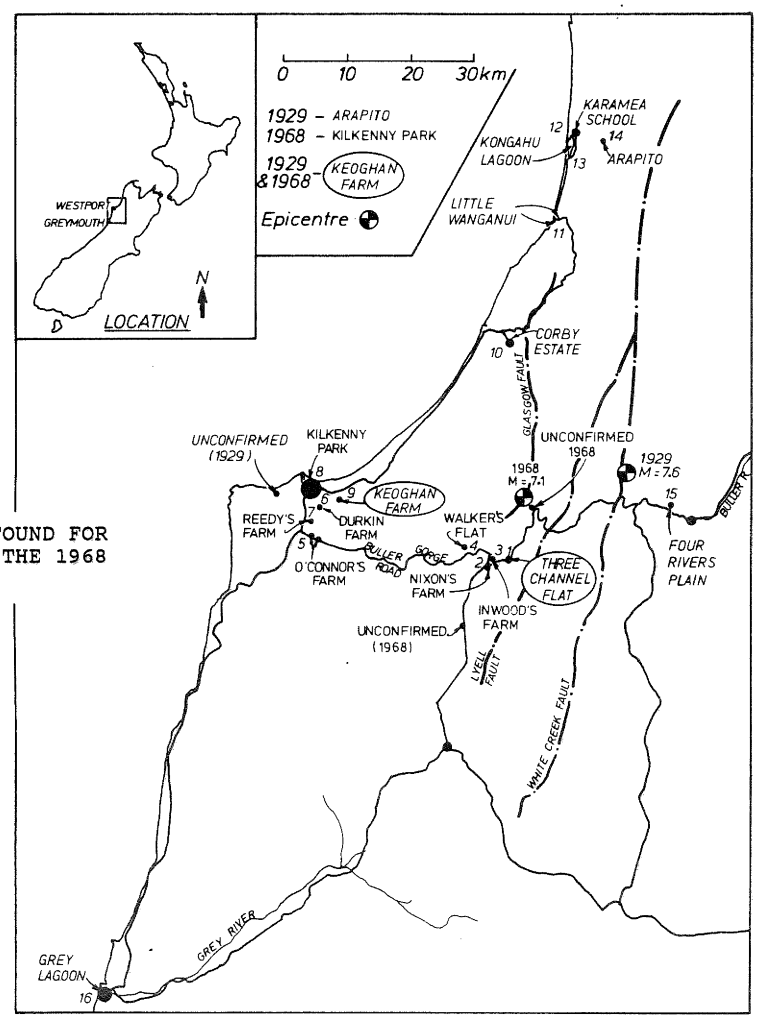

FIGURE 2: SITES OF LIQUEFACTION FOUND FOR THE 1929 MURCHISON AND THE 1968 INANGAHUA EARTHQUAKES.

TABLE 1: SITES OF LIQUEFACTION FOUND FOR THE 1929 AND 1968 BULLER EARTHQUAKES

SITE	EARTH-QUAKE	EPICENTRAL DISTANCE	EVIDENCE
1. Three Channel Flat, Inangahua	1929 1968	23 km 10	Newspaper report Eyewitnesses, aerial photos
2. Nixon's Farm, Inangahua	1968	12	Eyewitnesses, aerial photos
3. Inwood's Farm, Inangahua	1968	11	Eyewitnesses, aerial photos
4. Walkers Flat, Buller Gorge	1968	12-15	Eyewitnesses, aerial photos
5. O'Connor's Farm, Westport	1968	30	Eyewitness report; MM Intensity report.
6. Durkin's Farm, Westport	1968	32	Eyewitness
7. Reedy's Farm, Westport	1968	33	Eyewitness
8. Kilkenny Park, North Beach Area, Westport	1968	34	Several eyewitnesses, Newspaper reports & photos
9. Keoghan's Farm, Sergeants Hill, Westport	1929 1968	45 29	Eyewitnesses
10. Corby Estate, Seddonville	1929	27	Eyewitness
11. Little Wanganui	1929	41	Eyewitnesses
12. Karamea School	1929	54	Several eyewitnesses
13. Kongahu Estuary, Karamea	1929	51	Indirect eyewitness report
14. Arapito, Karamea	1929	52	Eyewitness
15. Four Rivers Plain, Murchison	1929	8	Eyewitness
16. Grey Lagoon, Greymouth	1929	114	Newspaper report

The main evidence for liquefaction in all cases was the ejection of sand. At one site, Kilkenny Park, Westport, this was accompanied by large-scale mass movement and by the toppling of electric power poles.

By far the most extensive occurrences of liquefaction were found in the flood plains of the Buller River at Three Channel Flat, about 3km northeast of Inangahua Junction, and at Walker's Flat, about 5km west of Inangahua Junction. Several hundreds of sand boils show up on aerial photographs taken on May 29 and 30 and in terrestrial photographs taken by various observers. In both places, the ejection of sand was quite pervasive. Figure 3 gives the flight plan of the post-earthquake aerial photography flown by New Zealand Aerial Mapping Ltd. The pilot was Mr Cyril Whittaker who confirms that runs A and B shown in the plan were not flown, due to poor weather.

Note that at least two sites, Three Channel Flat and Keoghan's Farm liquefied in more than one earthquake. Furthermore, one site near Meddows' Farm, Walkers Flat, liquefied in an aftershock of the 1968 earthquake as well as in the main shock.

Three unconfirmed sites are also marked in Figure 2. For these there is some indefinite evidence for liquefaction in 1968 in the form of vague word-of-mouth reports or apparently ejected sand in aerial photographs that could not be confirmed on the ground.

In the following paragraphs each site will be discussed in more detail.

Three Channel Flat

Extensive ejection of sand was observed at Three Channel Flat following the 1968 earthquake. The flat comprises a system of low terraces of Recent alluvium. The photograph shown in Figure 4 was taken on the day after the earthquake. The present owner of the land, Mr Warren Inwood, also remembers seeing the ejected sand, although he did not own the land himself at the time. The extent of sand ejection is clear from Figure 5, a vertical aerial photograph taken 5 days after the earthquake.

The flat comprises a system of low terraces of Recent alluvium. Extensive hand auger boring at the south end of the flat shows a layer of silt 3 to 4m thick overlying fine sands of variable thickness over gravels (Ooi, 1987; Adlam, 1988). Thickness of the sand layer increases towards the outside of the abandoned south channel evident in Figure 5, and decreases towards the inside of the channel, marked by the absence of sand boils. It appears that where there is sand, it was ejected in 1968.

The paddocks to the north of the central vehicle track have been extensively regraded since 1968 and their contours changed markedly. But to the south of the track the terrain is essentially the same, although some fences have been moved. The two paddocks at the south end of the flat (in the foreground of Figure 4) have been ploughed two or three times since 1968 yet in them it is still possible to pick up lenses of fine grey sand, presumably the ejecta, starting at depths of up to 200mm below the ground surface. After ploughing, while the soil is still moist, Mr Inwood reports that the patches of grey sand stand out markedly from the darker silts. The sand possibly owes its being buried to the ploughing, but possibly also to a build up of silt since 1968, as the paddocks are flooded about once a year.

Of the various sites of liquefaction in 1968, Three Channel Flat was the most extensively studied at the time.

Sutherland (1970) notes that patches of ejected sand occurred either in a linear arrangement with a fissure linking the flows or in a random pattern with no linking fissures. Presumably the formation of the linear fissure with sand ejection indicated some lateral mass movement, while the unconnected random pattern of boils, which he notes were found at Three Channel Flat and Walkers Flat, mark areas of complete liquefaction on virtually level ground.

Dodd and Dunlop (Dodd, 1970; Dunlop, 1968) investigated sand boils at the south west of the flats with auger borings and sieve analysis. The log of their boring, starting from the bottom of a recently excavated trench, is shown in Figure 6; grain size distributions of the ejected and subsurface sand strata are shown in Figure 7. Note the similarity of the sand gradings. Presumably the ejected sand came from the lower layer, below the water table.

Liquefaction also occurred at Three Channel Flat in the 1929 Murchison earthquake according to an article in the June 19, 1929 issue of the Wellington "Evening Post", which reports "Paddocks at Three Channel Flat are covered with white sand".

Sand Ejection near Inangahua Township

The confluence of the Buller and Inangahua rivers near the Inangahua township is marked by large areas of young alluvial river terraces. There are several contemporary reports (Lensen and Suggate, 1968; Adams et al., 1968, Sutherland, 1970; Dodd, 1970) of sand boils on these terraces in 1968; and patches of sand show up well on the aerial photographs. Figure 8, drawn up from the photographs, shows the areas in which ejected sand is apparent.

Sutherland (1970) reports a witness's account of water gushing to a height of 3m in the fields immediately to the north of Inangahua and that the "gusher" was active for at least an hour and a half after the earthquake.

Walkers Flat

Aerial photographs from runs C and D of the 1968 post earthquake photography show ejected sand over a large part of Walkers Flat. Figure 8 shows the extent of the 1968 sand boils.

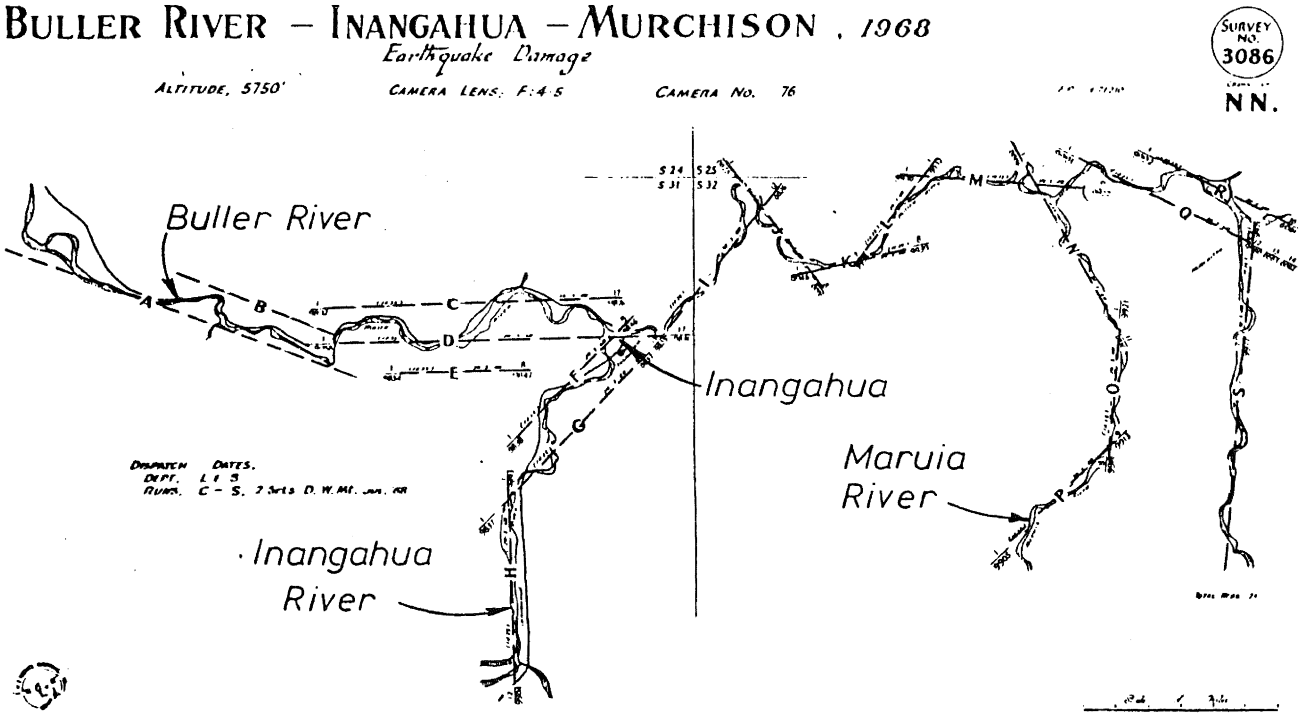

FIGURE 3: FLIGHT PLAN OF AERIAL PHOTOGRAPHY, SURVEY NO. 3086, FLOWN ON THE 29TH AND 30TH OF MAY, 1968.

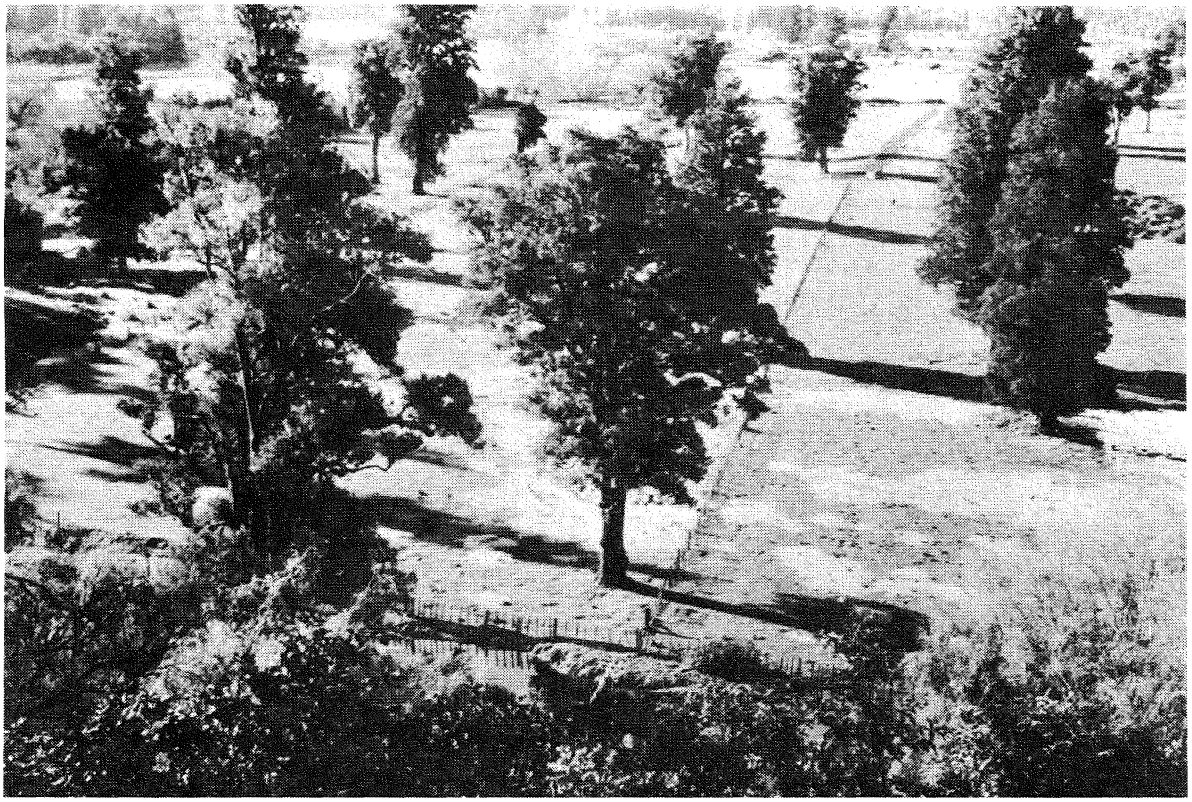

FIGURE 4: THREE CHANNEL FLAT, LOOKING NORTH FROM DEE HILL, THE DAY FOLLOWING THE 1968 EARTHQUAKE. NOTE THE EJECTED SAND AND VENTS VISIBLE IN THE FOREGROUND. (PHOTO: M. CALLAGHAN).

FIGURE 5: THREE CHANNEL FLAT, MAY 29, 1988.

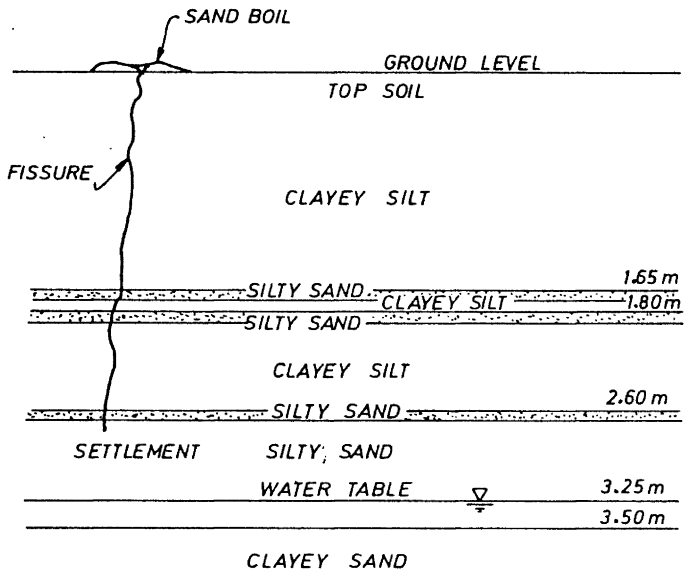

FIGURE 6: LOG OF TRENCH AND AUGER BORING BY DODD AND DUNLOP IN AUGUST 1968.

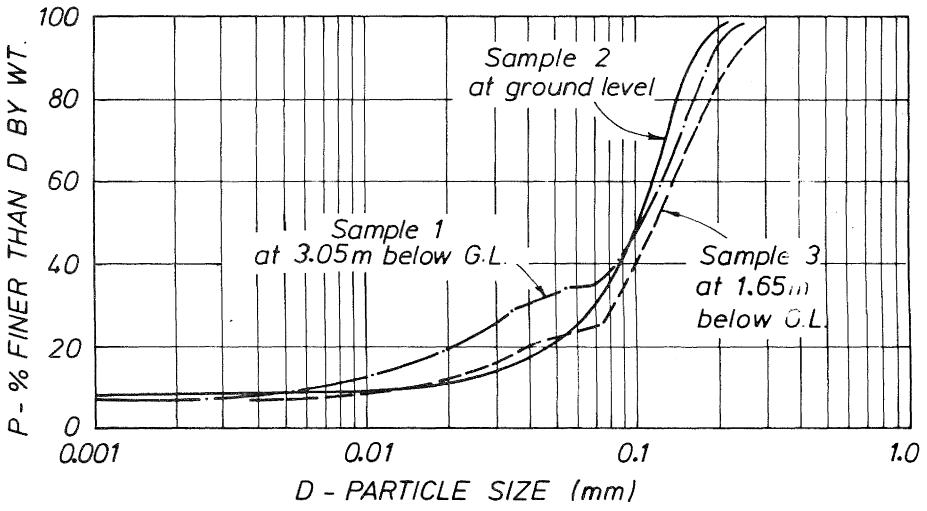

FIGURE 7: PARTICLE SIZE DISTRIBUTION OF SAMPLES TAKEN FROM BORING SHOWN IN FIGURE 6.

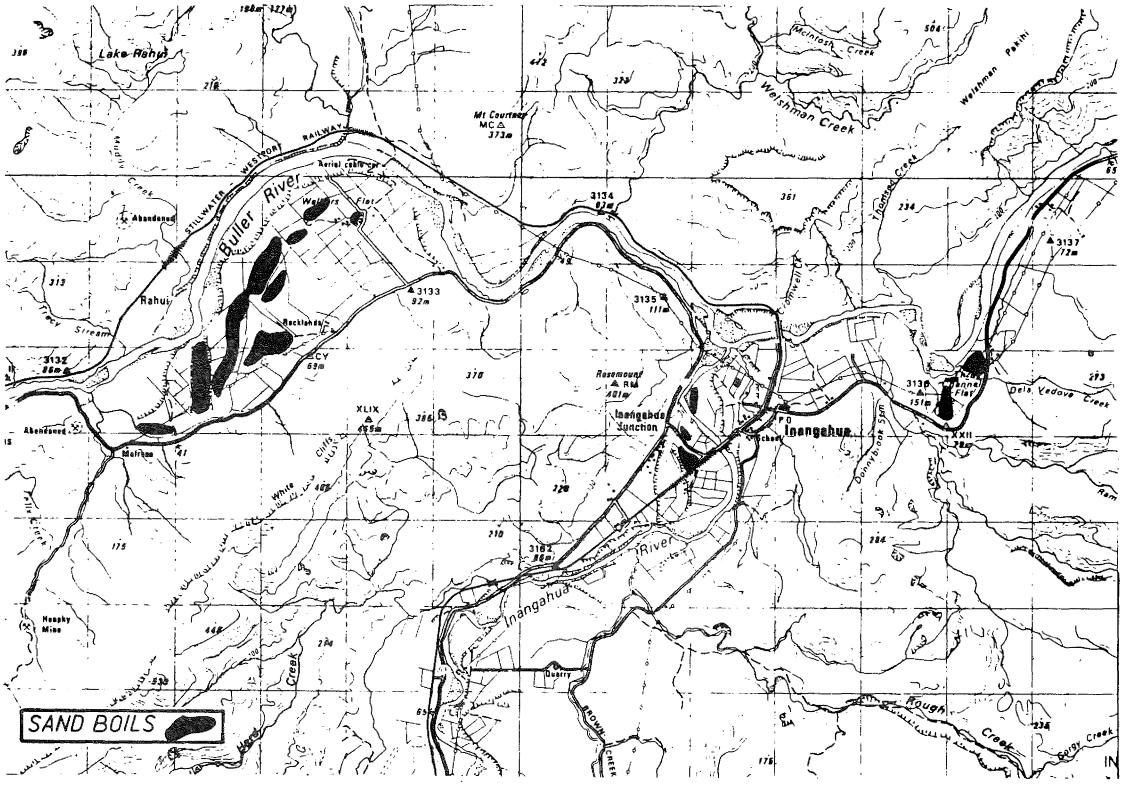

FIGURE 8: LOCATION OF EJECTED SAND SHOWING IN THE 1968 AERIAL PHOTOGRAPHS AT SITES NEAR INANGAHUA.

The eyewitness accounts and photographs taken near Mr G. Meddows' farmhouse at the east end of the flat are of particular interest. The photographs in Figure 9 show sand boils in the paddock immediately to the north of the farmhouse. Mr Meddows remembers sand and water being ejected from vents in the vicinity of the farmhouse and cowshed during some aftershocks as well as the main shock. But he did not notice any sand ejection in the area following the 1962 Westport earthquake sequence.

Keoghan Farm, Sergeants Hill

Mr Noel Keoghan's farm is situated on the banks of the Orowaiti River, south east of Sergeants Hill. His house is marked on Figure 10. Mr Keoghan observed sand boils in the paddocks to the north of his house following the 1929 earthquake and again in 1968.

From 1929, when he was a boy of 11, Mr Keoghan remembers geysers of sand and water 5 to 6 feet high, leaving sand cones 2 to 3 feet high. In 1968, smaller cones were formed, about 6 inches high, in the same general area. Small sand boils were also observed by Mr Keoghan in the bed of the Orowaiti River immediately to the south of his house. Mr Keoghan's daughter, Mrs Wayne Meddows of Whitecliffs, also observed the 1968 boils in the Orowaiti River, known locally as Giles Creek.

Mr Keoghan also observed premonitory behaviour amongst his livestock immediately before the 1968 earthquake. At the time, he was bringing in his cows for their morning milking. It was dark and he was passing a shed housing pigs. First the pigs started to squeal; about 3 seconds later the cows stampeded; then Mr Keoghan was thrown to the ground by the earthquake. Following the earthquake there was a strong smell of sulphur and the sound of many landslides in the surrounding hills.

O'Connor Farm, Buller Gorge Road

Mr John O'Connor observed sand boils in two places on his farm following the 1968 earthquake. They were:

1. On the Buller River side of the farm road immediately beyond where it crosses Omanu Stream.

2. On the flat paddock near the mouth of the Buller Gorge, beyond the cowshed.

Both sites are marked on Figure 10.

We were led to Mr O'Conner by a MM Intensity report, returned by him in 1968, in which he reported, among other things, "water and sand forced up through the ground".

Durkin Farm, Excelsior Road, Westport

Mr James Durkin observed the ejection of sand in the backyard of his house (now occupied by his son Michael) on Excelsior Road. Mr Durkin was not sure whether this occurred in 1962 or 1968. However, Mr O'Connor, who first told us of this site, implied it occurred in 1968. The house is marked in Figure 10.

Reedy Farm, Victoria Road, Westport

Mr John Reedy observed two large sand boils and several smaller ones in a low-lying paddock adjoining Victoria Road in 1968. A hand auger boring to 4.5m found a uniform fine sand below 1.6m of clayey silt, with the water table at approximately 1.4m.

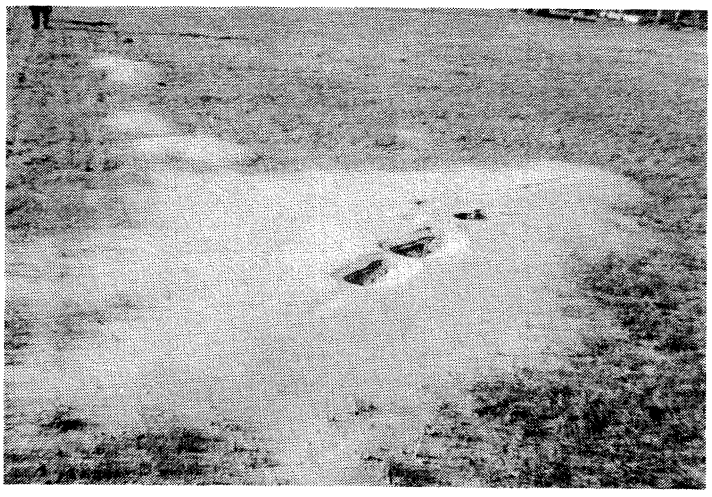

FIGURE 9A: SAND BOILS IN THE "BULL PADDOCK" MEDDOWS' FARM AT NORTHEAST END OF WALKERS FLAT, MAY 1968.

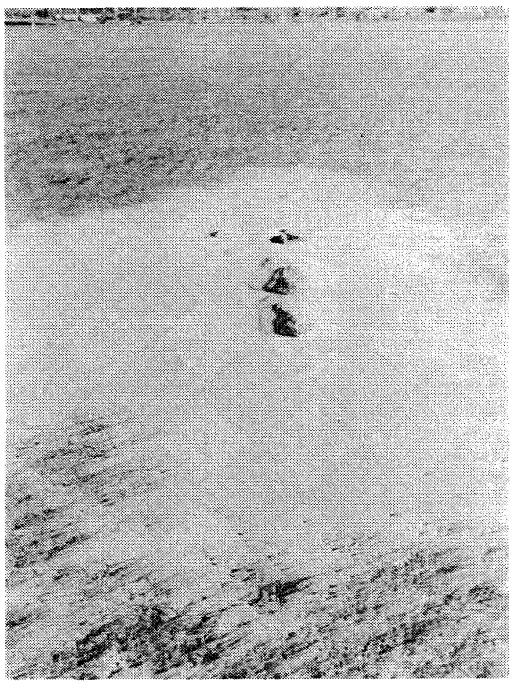

FIGURE 9B: DIFFERENT VIEW OF BOIL ABOVE. (PHOTOS: MRS WAYNE MEDDOWS, MR G. MEDDOWS).

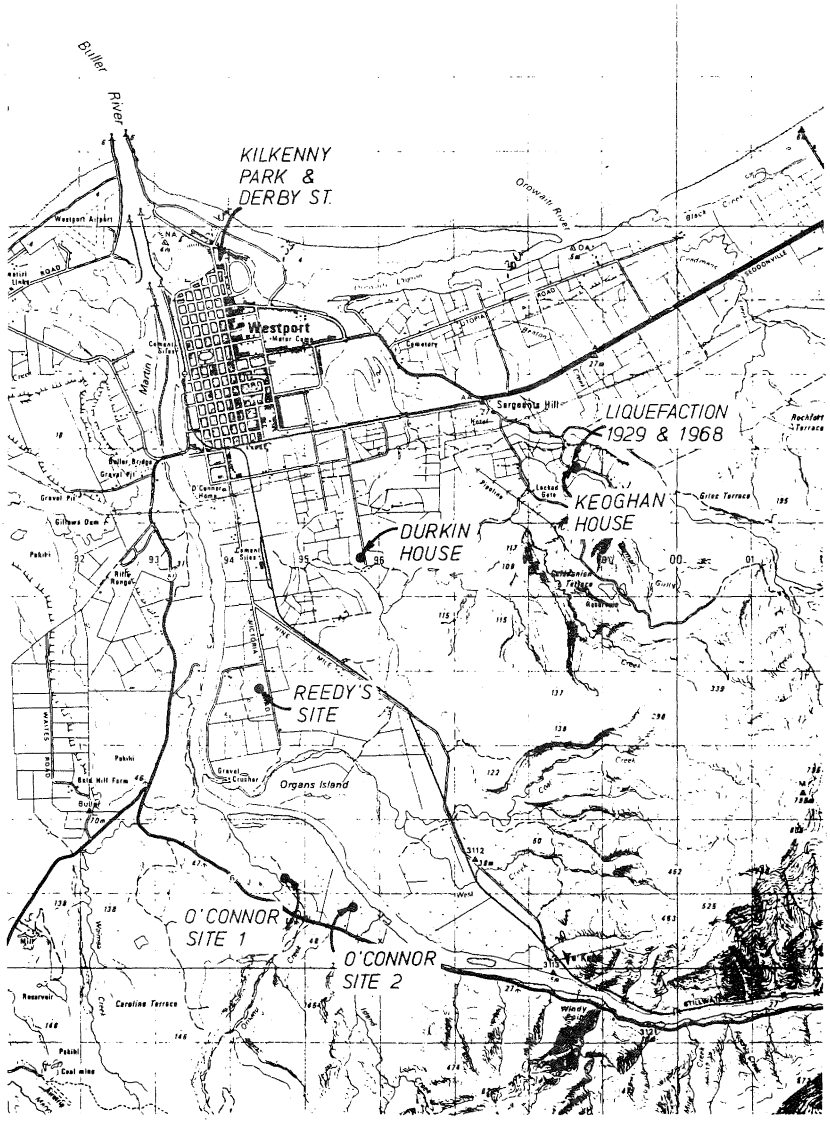

FIGURE 10: SITES NEAR WESTPORT.

Kilkenny Park area, Westport

Extensive sand ejection and some mass movements of soil took place in 1968 in the northern part of Westport surrounding Patterson and Kilkenny Parks.
Mr M. Dyer remembers seeing numerous sand boils in the paddocks immediately north of Shelswell St and over the land to the west of Patterson Park south of Orawaiti Road, as shown in Figure 11. He also remembers boils along the east side of Derby St at Kilkenny Park. Several other eyewitnesses reported sand and water boiling from the ground in Kilkenny Park; these include Mrs McDonald of Morgan's Lane, and Mr and Mrs Bill Gaynor and Mrs Naylor of Shelswell Street, whose properties back onto Kilkenney Park. They do not remember seeing anything similar in 1962, but Mrs Naylor has a less than certain recollection of seeing sand ejected during 1968 aftershocks.

Also, cracks opened in the ground passing through the Gaynors' house at 14 Shelswell Street and others on the south side of Shelswell Street. The cracks were roughly parallel to Shelswell St, (and to the nearby beach) and were of the order of a few hundred millimetres wide. Mr Gaynor, employed by the Westport Borough Council at the time, remembers having to add 1.2m of pipe to reconnect the broken water main running approximately north-south along Derby St, near Kilkenny Park. Taken together with the cracking, the broken water main suggests that a large mass of surficial soil had moved towards the coast on a layer of liquefied sand.

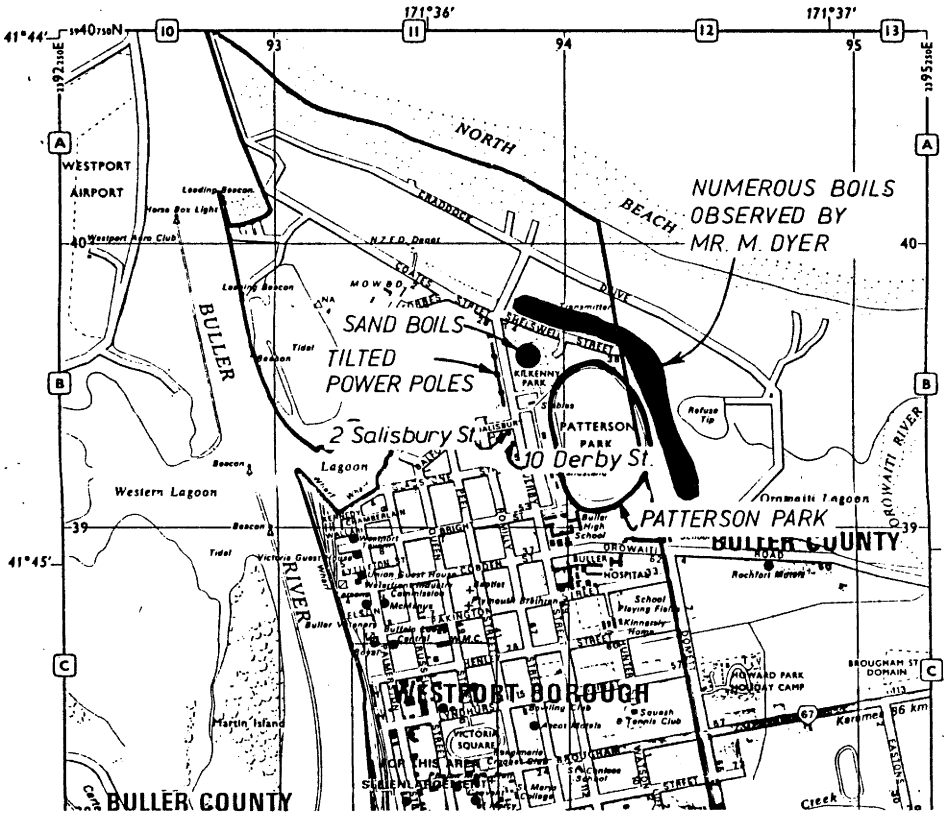

FIGURE 11: AREAS OF LIQUEFACTION IN 1968 IN THE KILKENNY PARK-NORTH BEACH AREA OF WESTPORT.

At Patterson Park itself, the "Nelson Evening Mail" of Friday 31 May, 1968, reports several fissures on the race track and a large 6m by 8m "boil up" of sand and water at the entrance to the front straight of the inside training track. The report has photographs of both the sand boil and fissures.

To the west of Patterson Park at 10a Derby St, sand erupted under a house with sufficient force to lift it, rotate it and leave it skewed on its foundations. (The house was subsequently demolished. The position of the 1968 boil and house was in front of the present house at number 10a).

Another sand boil was seen by Mr James Fischer to erupt in the grass verge in front of the house at 2 Salisbury Street, in 1968. A less definite report also had water coming out of the ground somewhere near 23 Romily Street, in the same general area.

Figure 12 shows tilted electric power poles on the west side of Derby St adjacent to Kilkenny Park, also pointing to liquefaction at a shallow depth.

No reports of liquefaction effects were found for sites to the south of this area in the town of Westport in 1968. This may be attributed to a greater susceptibility

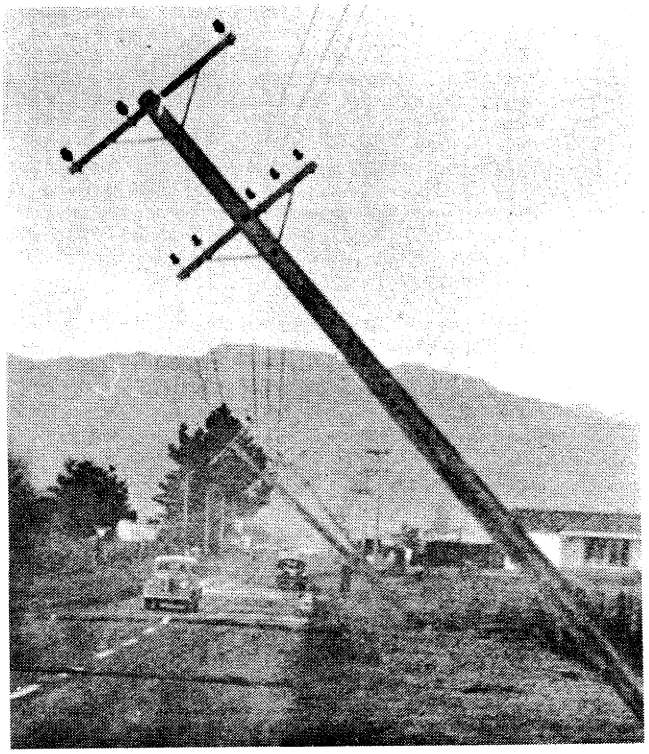

FIGURE 12: DERBY ST, WESTPORT, LOOKING SOUTH FROM KILKENNY PARK.

to liquefaction of the dune sands found to the north of Orowiti Road compared with the alluvial deposits found to the south. (Suggate and Wood, 1979) report that the boundary between dune sands and river-born sediments lies roughly along Orowaiti Road). It should also be noted that the dune sands from about Kilkenny Park north have been deposited very recently, following extensions to the harbour breakwaters in the 1890's.

Corby Estate, Seddonville, 1929

Mrs Corby remembers seeing sand boils on the Mohikinui River terraces between the Corby homestead and the Seddonville road. She could not locate the boils precisely, after 57 years, but they were in the area shown in Figure 13.

Little Wanganui area, 1929

Mr and Mrs R. Duncan of Little Wanganui can both remember seeing sand boils following the 1929 earthquake, at the approximate locations shown in Figure 14.

Karamea area, 1929

Sand boils were observed at several places around the Karamea township and further up the Karamea River valley. Also, in numerous places, water and sand was exuded from cracks in the ground, especially in road and railway embankments, indicating liquefaction-driven spreading phenomena.

Karamea School

The most frequently commented-on site was the Karamea School and the adjacent Domain sports field, shown in Figure 15. The 1929 earthquake occurred during school hours and many of the elder present-day residents of the district were then at school. Three eyewitnesses independently referred us to a site immediately in front of the old school building, where sand and some gravel was ejected. An auger boring made at the school in May 1987 (Bienvenu, 1988) found a gravelly coarse sand, answering the general description of the ejecta, from a depth of about 2 to 3m and overlain by silts and clays. The water table was at a depth of 2.2m in May 1987.

Sand boils and the ejection of sand from cracks were also reported elsewhere in the school grounds and in the paddock across the road to the north of the school.

Anderson's Farm, Arapito, 1929

Mr Cyril Lineham of Arapito, then a school boy at the Arapito school, remembers seeing sand and water together with some gravel ejected in the land to the south of the present road at Arapito at the location labelled "Anderson's Farm" (after the present owner) in Figure 15. Auger borings at the site indicated by Mr Lineham found coarse sand, overlain by sandy silts from a depth of about 2m. The coarse sand contained some small pebbles, from 15 to 30mm in size, consistent with Mr Lineham's description of the ejected material.

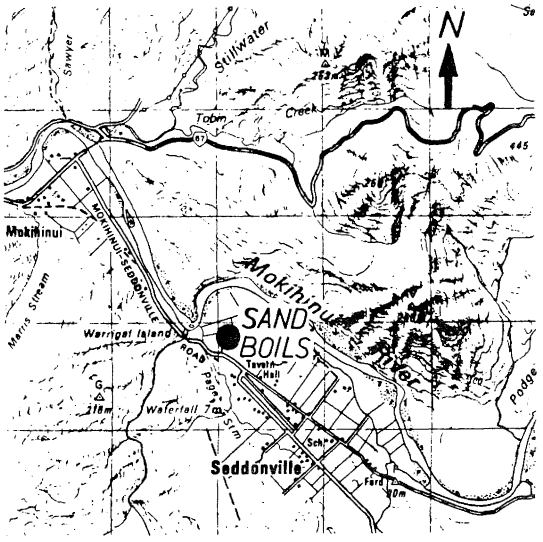

FIGURE 13: APPROXIMATE LOCATION OF SAND BOILS SEEN AFTER THE 1929 EARTHQUAKE.

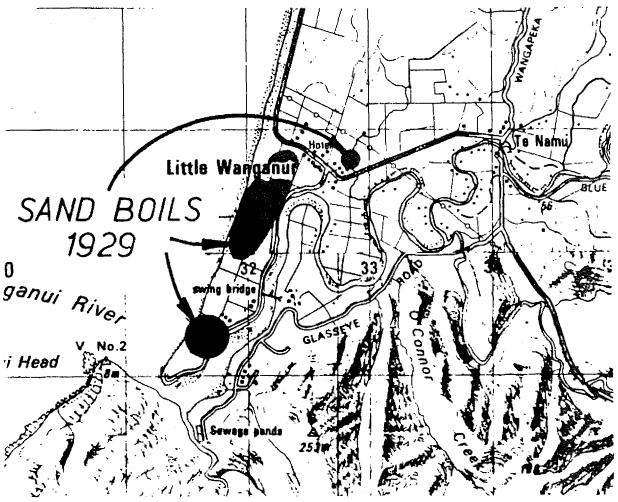

FIGURE 14: APPROXIMATE LOCATION OF SAND BOILS SEEN NEAR LITTLE WANGANUI IN 1929.

Kongahu Mudflats, Karamea, 1929

Although he was away from Karamea at the time, Mr Karl Jones clearly remembers his grandfather describing sand boils erupting around him in the estuary between Kongahu and Maori Point, where he was fishing at the time. The rough location is shown in Figure 15.

Near Karamea Golf Course, 1929

As well as remembering sand ejection in the school grounds, Mr Johnson also recalls a line of fence posts toppled just to the west of the pond between the aerodrome and the coast, immediately south of the present golf course. The approximate location is shown in Figure 15.

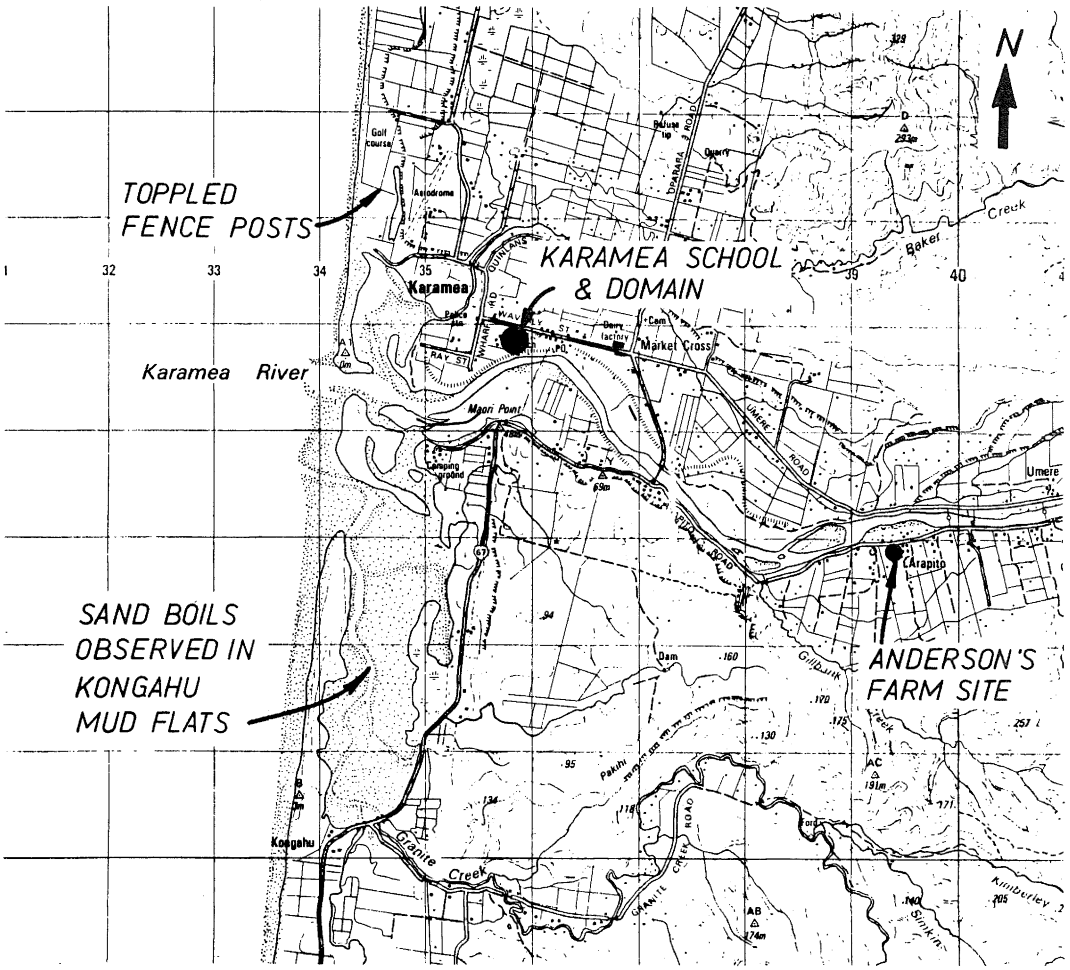

FIGURE 15: SITES OF LIQUEFACTION IDENTIFIED IN THE KARAMEA DISTRICT FOR THE 1929 EARTHQUAKE.

Monahan's Farm, Murchison, 1929

Mr T. Monahan remembers seeing sand boils distributed over the flat land around his house at Four Rivers Plain west of Murchison, and seeing isolated sand boils over most of the Four River Plain area after the 1929 earthquake. The Monahan's house and Four Rivers Plain are shown in Figure 16.

Mr Monahan did not see any boils following the 1968 earthquake, and a careful search of the aerial photos shows no sign of ejected sand at Four Rivers Plain.

Auger borings in the paddock immediately to the south of the Monahan house showed 500 to 700 mm of silt overlying a layer of very loose fine-to-medium sand, itself about 500 to 900 mm thick and underlain by gravel. The water table was not found above the gravel, but Mr Monahan reports that the water table has dropped appreciably since 1929. He also reports that this stratigraphy is fairly general on his farm, and that the present water table is generally at a depth of about 3m.

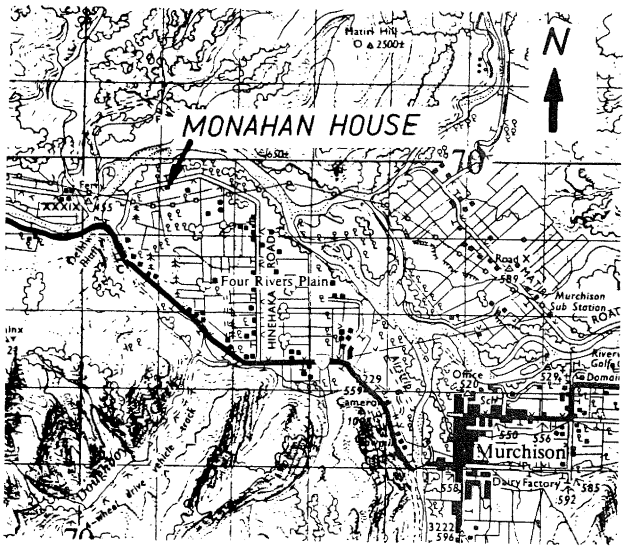

FIGURE 16: THE FOUR RIVERS PLAIN AREA WHERE PERVASIVE SAND EJECTION WAS OBSERVED IN 1929.

This suggests that either the water table was indeed considerably higher in 1929 or that the ejected sand came from a deeper layer. We note that the 1929 earthquake was preceeded by a long spell of exceptionally wet weather (Eiby, 1980), supporting the former supposition. Lowering of the water table may also explain the absence of liquefaction in 1968.

Grigg's Gravel Cone

A booklet by Grigg (1947) shows a photograph of a heap of gravel some 2 m high, which is claimed to have been produced by the 1929 earthquake. However a marginal note in a document shown to us by Mr and Mrs Monahan states that the gravel heap existed before the earthquake, and was presumably a stockpile of roading material.

Greymouth, 1929

The "Evening Post" of June 19, 1929 reports "At the south of the Grey Lagoon mud and sand were exuded during the big shock, and formed little hillocks on grass-covered areas. The fluid is straw-coloured, while the sand is of a different kind to that of the vicinity. One vent forced out a fence post." This clearly indicates the ejection of sand from well below the ground surface.

Unconfirmed Reports

Indefinite, generally third-hand reports were obtained of sand boils in 1929 between Carter's Beach and Cape Foulwind, near Westport, and in 1968 on Van Vught's Farm at Iron Bridge near Lyell. Also, the 1968 aerial photographs G 8 and 9 show white patches that may be ejected sand beside the Inangahua-Reefton road about 10 km south of Inangahua Junction. This land was owned by a Mr McLelland at the time of the earthquake, but he could not be traced and, as for the two other cases, no eyewitness confirmation of liquefaction could be found. These sites are marked in Figure 2.

MAGNITUDE-DISTANCE RELATIONSHIP

The 18 cases of liquefaction found in the Buller region are plotted on a magnitude-distance diagram in Figure 17, together with the Kuribayashi and Tatsuoka (1977) upper bound relationship for distance R_{max} to site of furthest liquefaction.

For the 1968 data, it is seen that liquefaction might have been expected at greater distances, especially towards the south, since the epicentre was at the northern end of the rupture surface. Enquiries were made of residents in the Reefton-Ikamatua area, but no further cases were found.

Amongst the 1929 cases, the most distant site, at Greymouth, plots on the bounding distance line, suggesting that this would be an especially interesting case to investigate further.

DISCUSSION AND CONCLUSION

Although there are few cases of liquefaction found in the technical literature for the 1968 Inangahua earthquake and none for the 1929 Murchison earthquake, liquefaction was quite common in both events. By making local enquiries

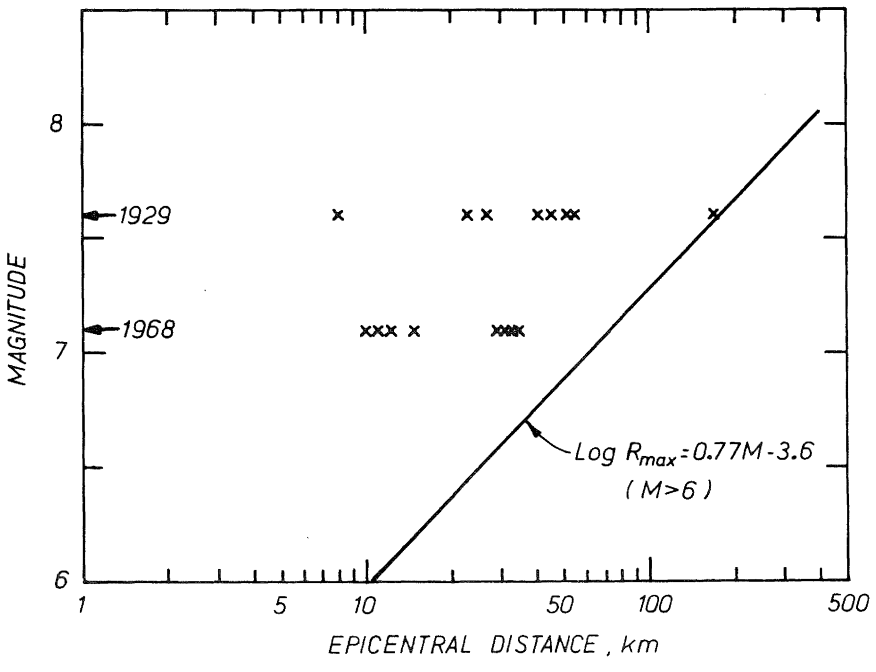

FIGURE 17: MAGNITUDE-DISTANCE PLOT OF THE 1929 AND 1968 SITES.

and searching newspaper accounts, 9 cases were confirmed for the 1968 earthquake and 9 also for the 1929 earthquake. Two sites, Three Channel Flat, Inangahua and Keoghan's Farm, Westport, liquefied in both events.

In the epicentral areas of both earthquakes extensive liquefaction occurred with sand being ejected over large areas of Walkers and Three Channel Flats in 1968 and over much of the Four Rivers Plain area in 1929. Reliquefaction occurred during at least one 1968 aftershock at Walkers Flat.

The most distant cases from the Inangahua earthquake occurred at Westport, 34 km from the epicentre. Here, sand was ejected at a few isolated places in the Buller and Orawaiti river floodplains and in a much more pervasive manner in the dune sands in the North Beach-Kilkenny Park area of Westport. It is worth noting that the greatest concentration of sand boils occurred in the very recent beach sands that have built up since the harbour breakwater extensions in the 1890's.

From the Kuribayashi and Tatsuoka criterion, we would expect liquefaction to be possible up to about 70 km from the epicentre given sufficiently loose soils. Enquiries of residents south of Reefton and Westport uncovered no further cases.

The extensive liquefaction in 1968 at Three Channel Flat and at Kilkenny Park and at Four Rivers Plain in 1929 suggest that these would be interesting sites to investigate further, as would the Grey Lagoon site if it can be located more precisely. And, in fact, work is in progress at the first two sites, to establish the soil properties there and to check the results of various predictive liquefaction models against the known occurrence of liquefaction.

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APPENDIX: SEISMOLOGICAL STUDIES

The 1968, M=7.1 Inangahua Earthquake

The M_L = 7.1 main shock occurred on May 23, at 1724 hours universal time (UT), corresponding to 5.24 am May 24, local time. The coordinates of the epicentre were 41.77# S, 172.01 E, with an approximate focal depth of 12 km north of Inangajua Junction, just to the west of New Creek. The epicentre lies at the NE of the aftershock region, which extends aoubt 45 km to the SSW over a band about 25 km wide to roughly the latitude of Rotokohu. Seismological aspects of the earthquake are discussed by Adams and Lowry (1971) and by Adams, Lowry and Ware (1971). The latter reference catalogues the 809 aftershocks, with M >= 3.0, recorded up to July 2, 1968. Twelve of these had magnitudes of 5 or greater.

The epicentral intensity was MM X; the MM IX isoseismal roughly encircles the aftershock region. Early aftershocks together with local isoseismals are shown in Figure A.1.

First motion studies by Adams and Lowry indicate a predominantly thrust mechanism, consistent with the small amount of surface faulting observed near Inangahua Junction (Lensen and Suggate, 1968). This is also in agreement with a separate study by Johnson and Molnar (1972) who conclude that the mechanism comprised a mixture of thrust and strike-slip motion, with the slip vector not well-determined. Robinson et al. (1975) and Rial and Cormier (1980) also discuss the Inangahua rupture mechanism.

Boyes (1971) reports ground displacements found from resurveys of the land survey network. He finds an area of uplift close to the area of aftershock epicentres, with a maximum uplift of 2.7 m occurring to the east of Inangahua.

The 1929, M = 7.6 Murchison Earthquake

The Murchison earthquake occurred at 2248 UT on June 16, 1929 on the White Creek Fault 12 km west of Murchison. The earthquake caused 17 deaths and much damage. The earthquake triggered an especially large number of landslides, aided by the steepness of the mountain terrain and the particularly wet midwinter weather of the preceeding weeks. An epicentral intensity of MM XI was recorded, and the shock felt throughout New Zealand.

Fault movement was oblique, but dominantly a thrust motion. Where the fault crosses the Buller Gorge road a vertical offset of 4.5 m was observed (Fyfe, 1929; Henderson, 1937), with a left lateral horizontal offset of about 2.5m (Berryman, 1980). The length of surface rupture does not appear to have been well explored, something that is understandable give the very mountainous and bush-clad terrain. Recent studies of landslide distribution (Pearse and O'Loughlin, 1985; Pearse and Watson, 1986) indicate that the rupture region was centered north of the Buller Gorge.

Eiby (1968) gives a magnitude of 7 3/4 and an epicentre of 41.8#S, 172.2#E. In a catalogue of revised magnitudes and epicentres, Smith and Berryman (1983) give the values of M = 7.6, and 41.7#S, 172.2#E, although Eiby (1980) gives the magnitude as 7.8. Perhaps these different values serve to indicate the uncertainties.

Further early studies of the earthquake were made by Ferrar and Grange (1929), Ferrar (1930) and Bastings (1933, 1935). Eiby (1980) gives a succinct general account of the very severe effects of the earthquake. The isoseismal map shown in Figure 1 was taken from Eiby's revised map, published in the undated report of Willett (about 1962).