ORMOND EARTHQUAKE LIQUEFACTION RECONNAISSANCE REPORT

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INTRODUCTION

On August 10 1993, at 09h 46m UT an earthquake of magnitude (ML) 6.4 occurred near Ormond, a locality to the north west of Gisborne in the North Island of New Zealand. The epicentre of the event was 38.52°S, 177.93°E, and had a focal depth of 48 km (Seismological Observatory, Institute of Geological and Nuclear Sciences Ltd.). Strong motion accelerographs at two sites on sediment in Gisborne recorded peak ground accelerations of 0.22 g at a distance of 20 km from the epicentre, while at Wairoa (80 km to the SW of the epicentre) 0.05 g was recorded, at Tolaga Bay (30 km to the NE of the epicentre) 0.09 g was measured [Pers. Comn. J. Zhou], and strong motion lasted for 5-10 s. Intensity of MMVI was observed in the Ormond area with pockets of MMVII, the later being based in particular on the presence of liquefaction.

While there was a small amount of minor structural damage in the form of minor damage to a few bridges [see Chapman, 1993], a number of toppled chimneys, and damage to an abandoned reinforced concrete freezing works structure, the main effects of the earthquake were geotechnical ones, principally liquefaction and small slope failures [see Read & Sritharan, 1993]. Liquefaction predominately occurred 20 km to the north west of Gisborne and also in a isolated site 8 km to the south west of Gisborne.

These cases of liquefaction appear to be particularly interesting because of the small magnitude of the earthquake and because of the large depth to the water table at some of the sites. It is likely that many of the sites were just over the limit of liquefying and will thus be of great use in calibrating empirical models. In addition, at those sites with a deep water table, liquefaction has necessarily occurred under high confining pressures, a condition for which there is a scarcity of data.

The aim of this reconnaissance study was to document the extent of liquefaction and to record the location of individual sand boils and to obtain samples of ejecta, for more detailed future studies. In addition, a number samples of ejecta were analyzed and typical particle size distributions are presented in this report.

The ejected material varies widely in its particle size,ranging from coarse silt to very fine gravel. The presence of ejected gravel adds to the interest of this earthquake.

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The location of the epicentre places three of the sand boils (W1-W3) near to the limit of Kuribayashi and Tatsuoka's (1975) lower bound for the maximum distance to liquefaction from the epicentre. Evaluating their expression:

$$\log_{10}R_{max} = 0.77M - 3.6 \qquad (R_{max} \text{ in km})$$

gives a maximum distance of 21 km, while the maximum distance to the observed liquefaction was 19 km. This observed maximum distance, combined with the relatively deep focal depth of 48 km, adds to the value that may be gained from this earthquake in the study of liquefaction.

Particle size distributions of some of the ejecta are interesting in the fact that they are close to the limits for easily liquefiable soils as proposed by Tsuchida (1971), as can be seen in Figure 8.

This report contains documentation on the areas were liquefaction occurred, termed sites; descriptions of particularly interesting ejecta; maps locating the positions of the sand boils; graphs of particle size distributions; and detailed description of individual sand boils, given in Table A.

SITE DESCRIPTIONS

The area to the north west encompasses five individual sites, which span 7 km of the Waipaoa River Valley between the towns of Te Karaka to the north and Ormond to the south (see Figure 1). The valley in this area is 1 to 2 km wide. The area of liquefaction to the south west of Gisborne is immediately inside the stop bank of the Waipaoa River. The liquefied areas are situated on some of the most recent terraces of the flood plain. While it was not possible to locate all sand boils in the short time allocated, it is believed that the majority are recorded in this article.

The generally hilly land to the north west of Gisborne is comprised of soft mudstone rock and is generally oversteepened. The topsoil of the Waipaoa Valley is generally composed of silt and clay loam lying at various terrace levels. This valley system is aggrading rapidly with silts due to the high erosion rates in the headwaters of the Waipaoa River. Erosion has been exacerbated by land clearing during the 150 years of European settlement. Water well logs across the Waipaoa Plains indicate sequential layers of sandy gravels and silts.

At Site 1 (see Figure 2, boils 1-18), the northern most site at which liquefaction occurred, the sand boils were contained to a strip of land within 150 m from the edge of the surrounding

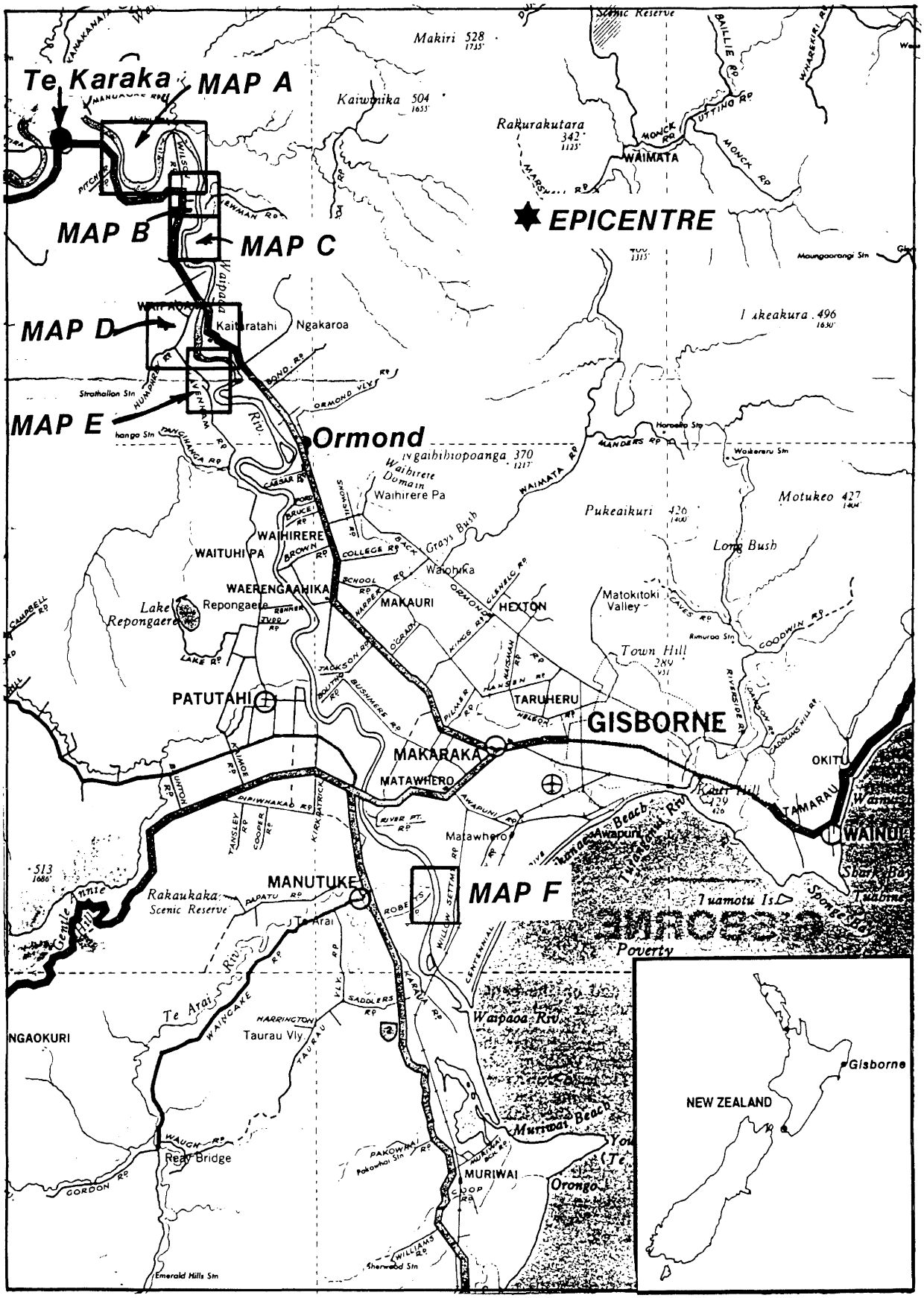

Figure 1 Overview Map showing areas affected by the Ormond Earthquake.

hills in a former meander of the Waipaoa River. There was surface water lying on some parts of the ground, resulting from a combination of ejected water and rain water (70 mm had fallen in the three days prior to the earthquake). A water well 300 m from the hills has a water level of 9 m below ground level. A 700 mm deep drain runs through the area of liquefaction with water flowing 100 mm deep in the bottom. Hand auguring to 3 m failed to locate the water table at boils 4 & 10, which are closer to the hills than the water well. The vents of the sand boils do not appear to be orientated in any particular direction.

Site 2 (see Figure 3, boils 19-23), lies on the true right bank of the Waipaoa River, just beside State Highway 2. These boils are also contained in a area next to the hill side and on top of a former river meander. The sand boils lie beside a drain which is about 3 m below the terrace level which had approximately 200 mm of water flowing in it four days after the earthquake. The vents of these boils were aligned in a SE-NW direction, which is perpendicular to the nearby hills.

Site 3 (see Figures 3 & 4, boils 24-48), lies on the true left bank of the Waipaoa River in a former meander. The sand boils lie on the inside of this former meander, at the eastern and southern ends. A stream now flows between the hills and the terrace which is 4 m below the terrace level. The sand boils on the eastern edge of the former meander (boils 24-39) have in general, a E-W tendency, while the ones on the southern edge (boils 40-48) have a N-S tendency. Information from the farmer suggests that this area has aggraded over 3 m in the previous 50 years and that the area was formerly a swamp.

Site 4 (see Figure 5, boils 49-71,75-104), is the most active in terms of the number of sand boils. This site lies on the true right bank of the Waipaoa River, near Waipaoa, with the sand boils running from the stop bank next to the river, to the base of the foot hills to the west about 1 km away. Many of the sand boils are aligned along the edges of former meander loops, while the remaining boils lie within the lower terraces and in some cases near the edge of the terrace on the next level. There were many small sand boils within the Waipaoa Drain, which is 2 to 3 m deep. The water table to the western side of the site, next to the foot hills (boils 57 & 61), was established at 0.800 m five days after the earthquake, while halfway towards the river (boil 76), hand auguring to 5 m did not locate the water table. Water well logs near the stop bank in this location had water levels of 19.2 m and 17.7 m seven days after the earthquake. A 50 mm galvanised water pipe buried 0.5 m deep was broken in the area immediately to the north of the former meander where no sand boils where apparent.

Site 5 (see Figure 6, boils 72-74) is on the true right bank of the Waipaoa River. This again is a site on one of the lower terraces in a former meander loop.

Site 6 (see Figure 7, boils W1-W3), is the most southern sites, situated to the south west of Gisborne on the true right bank of the Waipaoa River near Manutuke. This site is on the edge between a former meander in the river and the current river course. As well as these three boils, many more were spotted from a light aircraft by S Read (IGNS) in the area lying between Whites Drain and Manutuke East Drain, which are shown in Figure 7.

EJECTED MATERIAL

Samples of ejecta were recovered from a large proportion of the sand boils, with a total of 110 samples being retrieved. A summary of the ejecta and description of the sand boils is given in Table A. The results for particle size determination analysis of 18 samples undertaken at the University of Canterbury are represented in Figures 8-11. Most of the sand boils are linear in shape, often with vents well aligned (see Figure 12).

The two samples of ejected gravel (boils 4 and 82, see Figures 13 & 14), which were retrieved from the top of the boils, were most probably entrained in the ejected water from gravel layers above the layer of liquefied sand. The gravel was lying on top of uniform boils which consisted of well sorted fine grey sands. It should be noted that the gravel particle size distributions are not reliable as it is not possible to establish the matrix from which they were derived, although this does indicate the size of the larger particles.

Boil 14 (as seen in Figures 15 and 16) is unusual in that it is comprised entirely of very coarse sand and does not included any layers of finer material as is the case with most of the sand boils.

The majority of the sand boils were stratified with coarser particles on the bottom

and finer on top. This would indicate an upward progression of the liquefaction front to a more dense soil as observed by Scott and Zuckerman [1973] in the laboratory. A notable exception to the finer soil being liquefied last is seen at boil 61 (see Figure 17) where a medium brown sand overlies a thin layer of coarse grey silt.

The brown sands comprised about 35% of the ejected soils (grey soils making up the remainder), and were in general more poorly sorted than the grey, and often included pebbles.

Boils 55 and 56 contained a very small amount of ejected grey coarse silt (see Figure 18). These two boils were mainly comprised of topsoil, which was either fine particles which had been broken down by the percolating water or intact pieces of topsoil which had been lifted above the ground surface by the flowing water.

Approximately 15% of the sand boils had small traces of organics (see Figures 19 & 20) around the edges of the boils, while several kilograms were ejected from boil 30, and deposited around the edges. The sand boils with ejected organics were mainly confined to Site 3.

Around 30% of the sand boils at Sites 1 and 3 had traces of a yellow/brown silt which formed a foam (as reported by farmers) around the fringes of the boils, this was especially notable at boil 37. While sieving the soils, a smell of hydrogen sulphide was apparent for many of the samples.

In addition to these more unusual features, there were a large number of more normal sand boils whose characteristics are listed in Table A. Photographs of these more typical sand boils are shown in Figures 21 - 27.

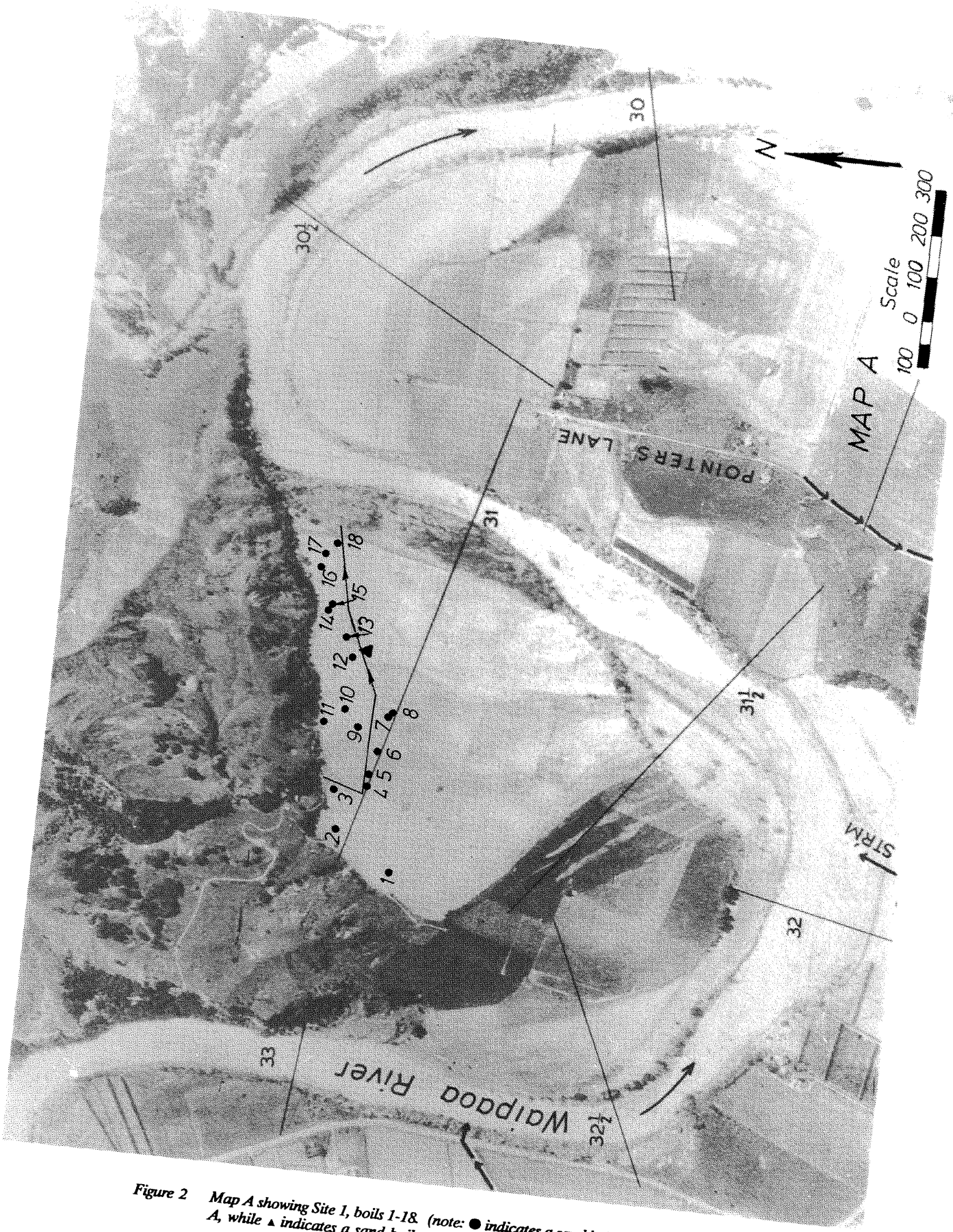

Figure 2 *Map A showing Site 1, boils 1-18. (note: ● indicates a sand boil documented in Table A, while ▲ indicates a sand boil not documented)*

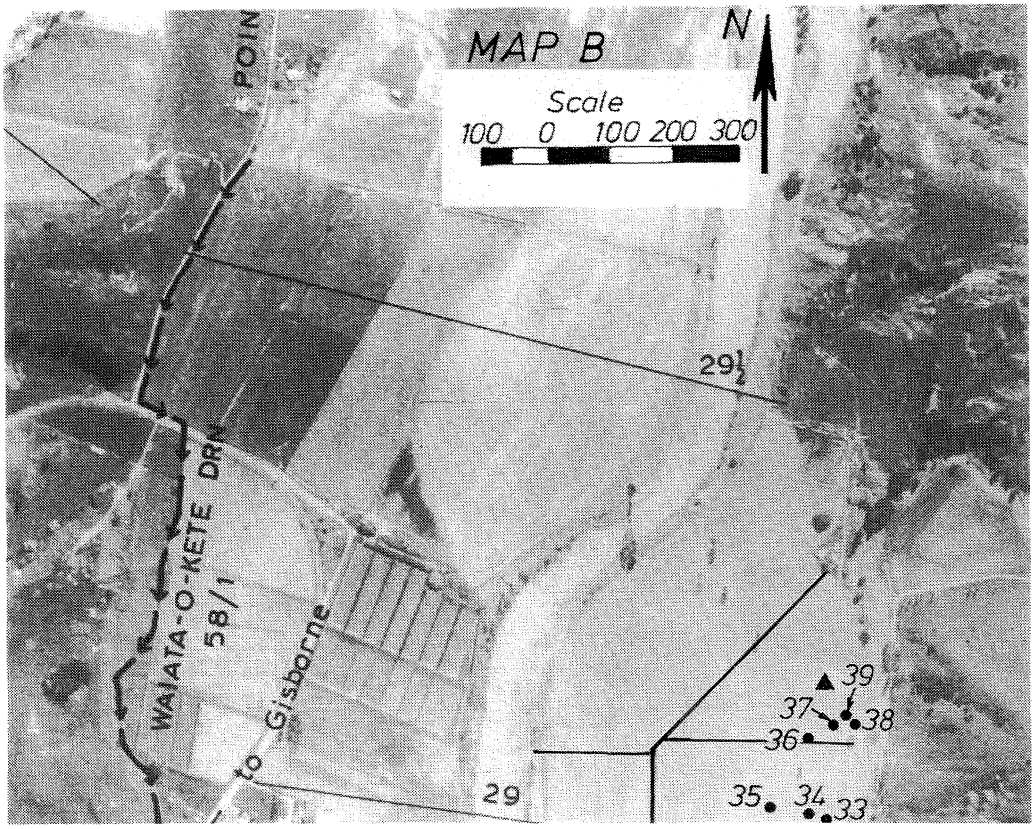

Figure 3 Map B showing Site 3, boils 33-39.

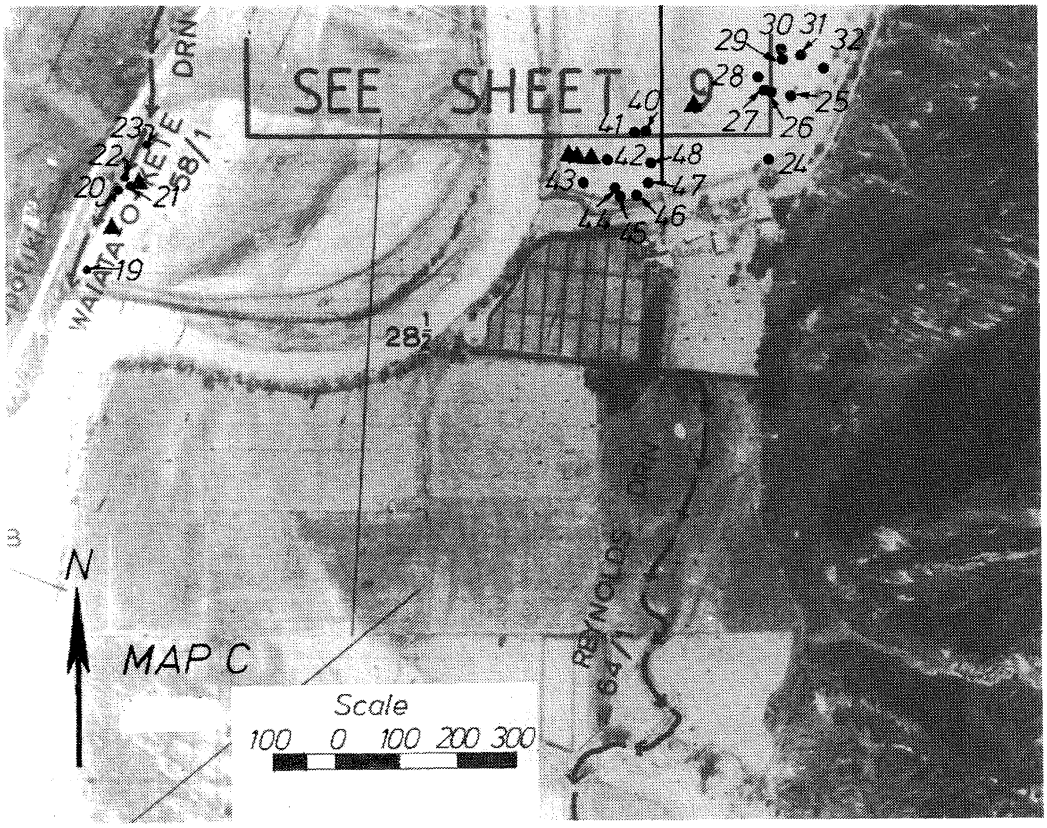

Figure 4 Map C showing Sites 2 & 3, boils 19-32 & 40-48.

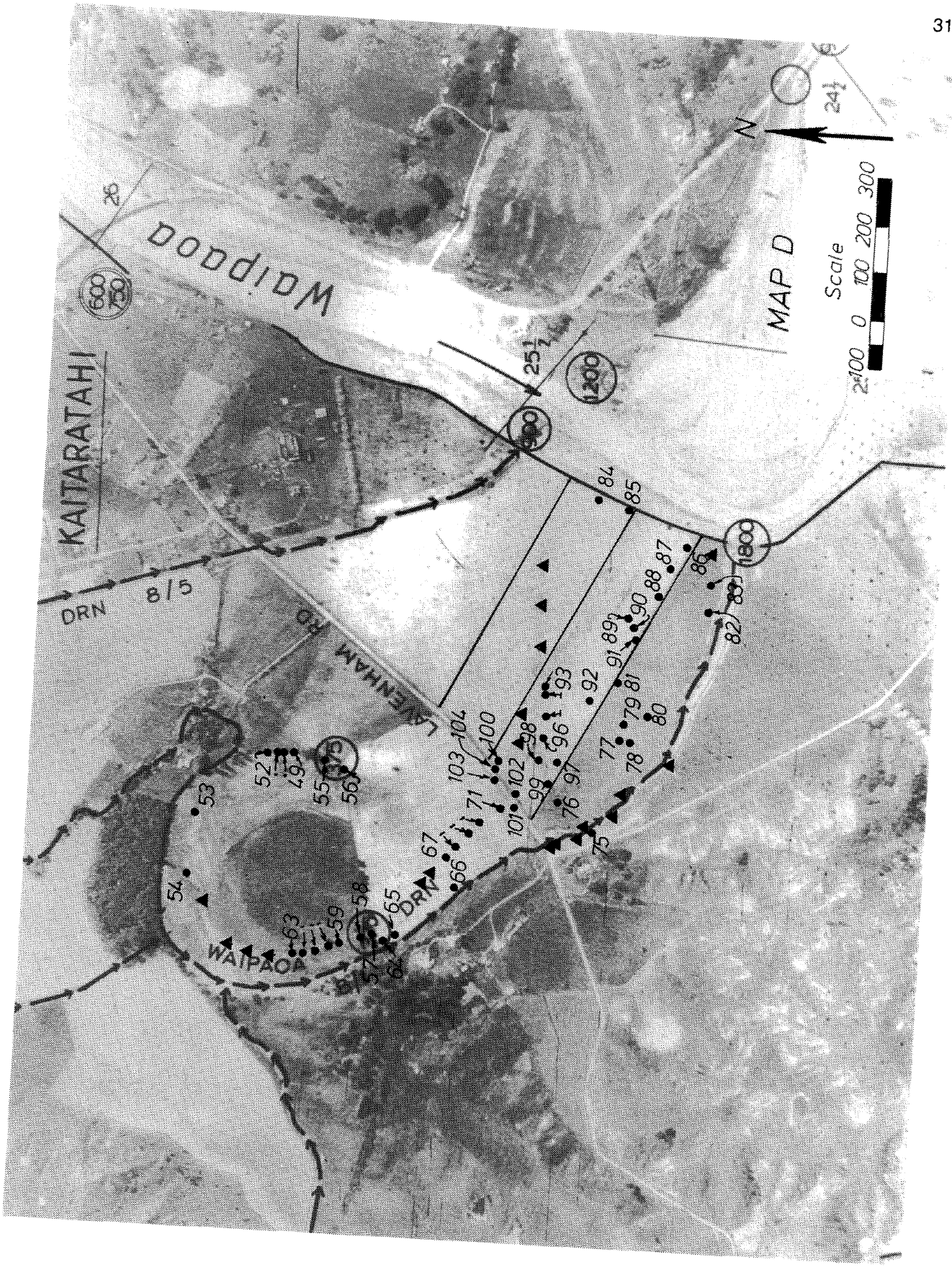

Figure 5 *Map D showing Site 4, boils 49-71 & 75-104.*

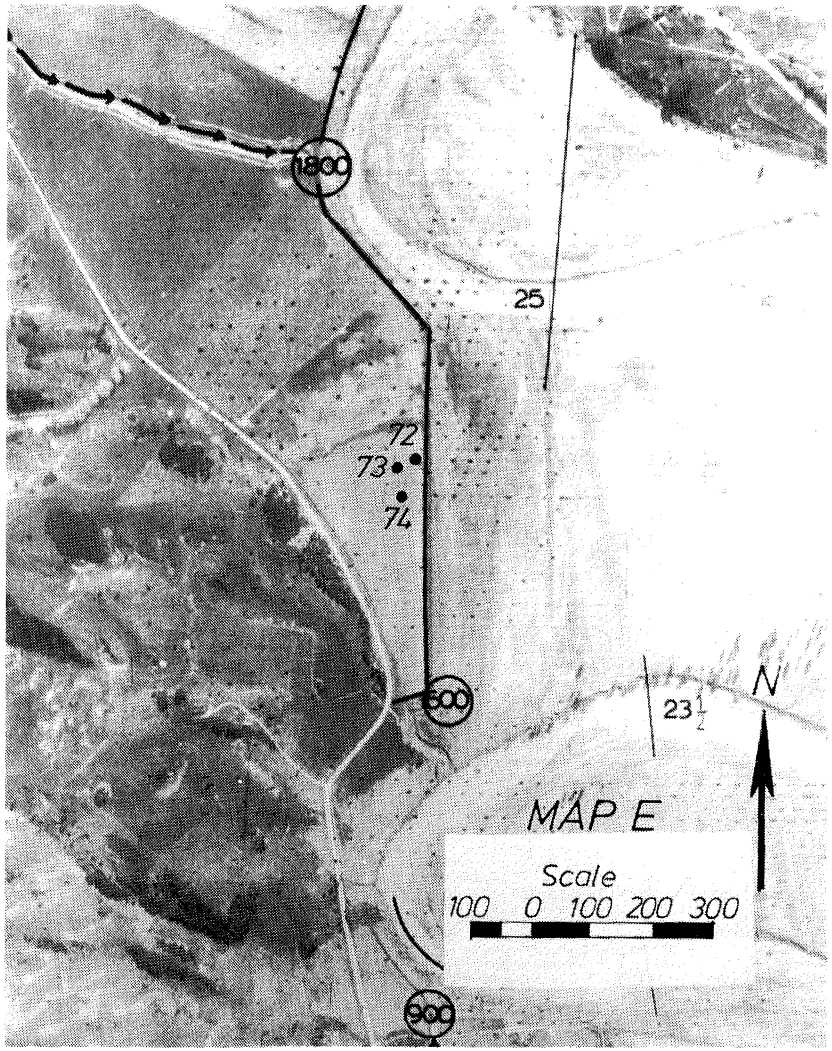

Figure 6 Map E showing Site 5, boils 72-74.

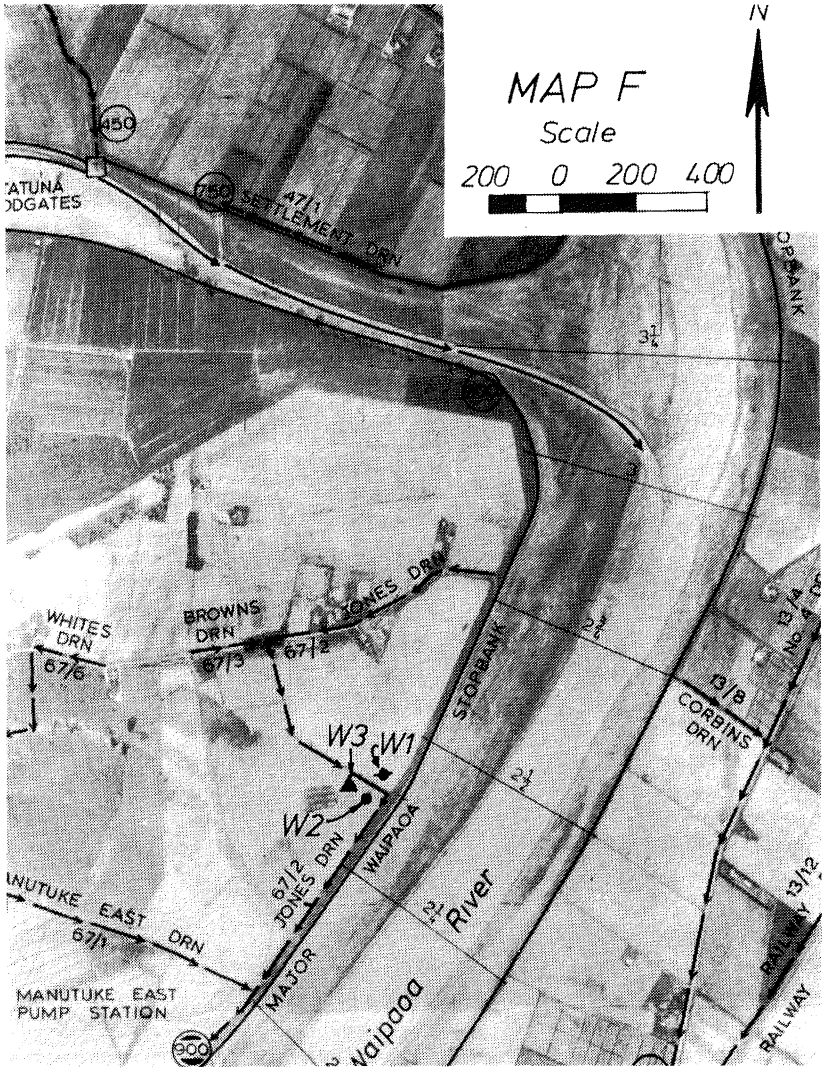

Figure 7 Map F showing Site 6, boils W1-W3.

BOIL #	MAP	BOIL SIZE[1]	FIELD DESCRIPTION[2]
1	A	7X3	Fine to very fine grey sand overlying well graded medium grey sand. Depth = 0.120 †‡
2	A	12x10	Poorly sorted medium sand with pebbles to 20 mm lying on a 10 mm layer of well sorted fine grey sand overlying a moderately well sorted medium sand. Depth = 0.120 †
3	A	4x2	Well sorted very fine grey sand overlying well sorted medium to fine grey sand. Depth = 0.100 †
4	A	24x8	Gravel to 55 mm in diameter lying on 60 mm of well sorted fine grey sand overlying medium grey sand. Depth = 0.200 †‡
5	A	7x8	Well sorted very fine grey sand overlying medium grey sand. Depth = 0.060 †
6	A	19x5	Poorly sorted medium grey sand with pebbles to 10 mm lying on 10 mm layer of moderately well sorted medium to fine grey sand overlying a 50 mm layer of moderately sorted coarse to fine grey sand. Depth = 0.075 †‡
7	A	1x1	Similar to Boil #6. Depth = 0.030
8	A	9x3	5 mm of grey very fine sand overlying moderately well sorted medium to fine grey sand. Depth = 0.050 †
9	A	9x1	Very sparse grey ejecta. Depth = 0.003
10	A	11x10	10 mm of very fine grey sand overlying well sorted fine grey sand, ejected organics near edge of boil. Depth = 0.100 †
11	A	7x1.5	5 mm of grey well sorted very fine sand overlying grey moderately well sorted medium grey sand. Depth = 0.100 †
12	A	21x6	Moderately well sorted fine grey sand with a minor amount of very fine grey sand. Depth = 0.050 †‡
13	A	2.5x0.5	Similar to boil # 12.
14	A	10x1.5	Poorly sorted very coarse grey sand. Depth = 0.050 †‡
15	A	6x1.5	10 mm very fine grey sand overlying moderately well sorted medium grey sand. Depth = 0.060 †
16	A	10x1.5	5 mm of very fine grey sand overlying moderately well sorted medium grey sand. Depth = 0.080 †
17	A	2.5x1	40 mm of grey well sorted very fine sand to coarse silt overlying a medium grey sand. Depth = 0.060 †
18	A	2x1	Similar to boil # 17.
19	C	45x3	5 mm of moderately well sorted very fine sand to coarse grey silt overlying moderately sorted medium to fine grey sand, with ejected organics near the edges. Depth = 0.100 †
20	C	10x10	100 mm of well sorted very fine grey sand overlying moderately well sorted medium grey sand. Depth = 0.170 †‡
21	C	33x2	Small amount of poorly sorted coarse sand lying on 3 mm of well sorted very fine grey sand overlying moderately well sorted medium grey sand. Depth = 0.170†
22	C	4x3	Small amount of poorly sorted very coarse sand (pebbles up to 8 mm) lying on well sorted fine grey sand to a depth of 10 mm overlying a moderately well sorted coarse grey sand. Depth = 0.150†
23	C	10x3	Well sorted fine grey sand overlying a moderately well sorted medium grey sand.†
24	C	13x6	Three equal layers of well sorted fine grey sand. Depth = 0.150†
25	C	11x6	25 mm of well sorted very fine grey sand overlying medium grey sand. Depth = 0.050†
26	C	20x3	Fine grey sand with ejected organics around the edges. Depth = 0.080†
27	C	6x5	Similar to boil # 26.
28	C	30x10	100 mm of well sorted very fine grey sand overlying well sorted medium brown sand. Depth = 0.140†
29	C	4x1	5 mm of very fine grey sand on top of well sorted medium grey sand. Depth = 0.050†
30	C	16x5	Well sorted fine grey sand overlying poorly sorted medium brown sand (pebbles up to 35 mm) with ejected organics near edges. Depth = 0.100†
31	C	11x3	Fine grey sand overlying brown/grey medium sand. Depth = 0.200
32	C	3.5x1.5	Medium grey sand.
33	B	16x5	Very fine grey sand overlying moderately sorted medium brown/grey sand. Depth = 0.180†
34	B	26x2	5 mm of very fine grey sand overlying medium brown sand with yellow/brown foam around the edges. Depth = 0.200
35	B	10x3	Moderately well sorted brown medium sand.†
36	B	16x8	Poorly sorted medium sand with occasional pebbles (5 mm).†

BOIL #	MAP	BOIL SIZE[1]	FIELD DESCRIPTION[2]
37	B	12x8	Moderately sorted medium sand with yellow/brown foam around edges. †
38	B	12x1	Well sorted very fine grey sand overlying moderately sorted medium grey sand.†
39	B	15x4	Medium grey sand.
40	C	9x3	Moderately sorted medium grey sand.†
41	C	12x4	Medium grey sand.
42	C	6x5	Well sorted fine grey sand.†‡
43	C	9x5	Medium grey sand.
44	C	12x4	Medium grey sand.
45	C	11x3	Poorly sorted fine to medium brown sand (with pebbles to 15 mm)†
46	C	9x3	Poorly sorted coarse to brown medium sand (with pebbles to 8 mm)†‡
47	C	20x20	Group of three vents: medium grey sand; fine grey sand; and 10 mm of very fine grey sand overlying 50 mm medium grey sand.
48	C	19x5	5 mm very fine grey sand overlying well sorted medium sand. Depth = 0.080†‡
49	D	3x1	Moderately well sorted medium to fine brown sand. Depth = 0.080†
50	D	6x3	Moderately well sorted medium to fine brown sand. Depth = 0.150†
51	D	5x4	Moderately well sorted medium to fine brown sand. Depth = 0.160†
52	D	4x1.5	Moderately well sorted medium brown sand. Depth = 0.080†
53	D	1x0.5	Moderately well sorted medium brown sand. Depth = 0.040†
54	D	10x8	Poorly sorted coarse sand. Depth = 0.005†
55	D	1x0.5	Ejected water, but no ejected soil.
56	D	1x0.5	Ejected water, but no ejected soil.
57	D	12x1	5 mm of very fine grey sand overlying moderately well sorted very coarse sand.†‡
58	D	6x2.5	5 mm of moderately well sorted very coarse grey sand overlying well sorted very fine sand. Depth = 0.050†
59	D	7x1	5 mm of very fine grey sand overlying moderately well sorted medium to coarse grey sand. Depth = 0.050†
60	D	10x1.5	3 mm of very fine grey sand overlying medium sand. Depth = 0.050
61	D	12x2	5 mm of fine grey sand under moderately well sorted coarse brown sand (pebbles to 15 mm). Depth = 0.075†
62	D	3x1	Coarse brown sand.
63	D	5x1	Well sorted very fine brown sand. Depth = 0.050†
64	D	5x5	Well sorted very fine grey sand. Depth = 0.030†‡
65	D	15x3	Well sorted very fine grey sand. †
66	D	3x3	Very small amount of grey ejecta.
67	D	17x3	30% of boil covered with very fine grey sand overlying a well sorted medium brown sand. Depth = 0.150†
68	D	16x3	40% of boil covered with very fine grey sand overlying a well sorted medium brown sand. Depth = 0.150†‡
69	D	13x8	80% of boil covered with very fine grey sand overlying a moderately well sorted medium brown sand. Depth = 0.150†
70	D	14x3	50% coverage of boil with 5 mm of very fine grey sand overlying moderately well sorted medium brown sand. Depth = 0.200†
71	D	16x5	90% coverage of boil with very fine grey sand overlying moderately well sorted medium brown sand. Depth = 0.150†
72	E	14x4	Traces of very fine grey sand overlying moderately well sorted medium to fine grey sand. Depth = 0.100†
73	E	27x8	Well sorted very fine grey sand overlying well sorted fine grey sand. Depth = 0.150†‡
74	E	8x3	Well sorted fine to very fine grey sand. Depth = 0.075†
75	D	4x3	Moderately well sorted medium grey sand with minor very fine sand. Depth = 0.050†

BOIL #	MAP	BOIL SIZE[1]	FIELD DESCRIPTION[2]
76	D	32x10	Well sorted medium grey/brown sand. Depth = 0.080†
77	D	19x3	Fine grey sand with minor very fine grey sand on top. Depth = 0.100
78	D	36x8	Moderately well sorted medium to fine grey sand with minor very fine sand on top. Depth = 0.150†
79	D	4x2	Moderately well sorted medium to fine grey sand with minor very fine sand on top. Depth = 0.080†
80	D	23x9	Well sorted fine grey sand with minor very fine grey sand on top. Depth = 0.120†
81	D	18x9	Well sorted fine grey sand with 5 mm of very fine grey sand on top. Depth = 0.100†
82	D	21x13	Well sorted fine grey sand with minor very fine sand and pebbles on top. Depth = 0.150†‡
83	D	15x4	Well sorted fine grey sand with minor very fine sand and pebbles on top. Depth = 0.150†
84	D	10x2	3 mm of very fine grey sand covering 50% of boil overlying medium grey sand. Depth = 0.300
85	D	10x8	3 mm of very fine grey sand covering 80% of boil overlying medium grey sand. Depth = 0.300
86	D	7x3	3 mm very fine grey sand overlying poorly sorted very coarse sand (pebbles to 10 mm). Depth = 0.050†‡
87	D	10x2	Very fine grey sand overlying moderately sorted medium sand. Depth = 0.090†
88	D	3x3	1 mm of very fine grey sand overlying moderately sorted medium sand. Depth = 0.080†
89	D	13x2.5	Well sorted medium grey sand. †
90	D	29x2.5	2 mm very fine grey sand with a few pebbles overlying well sorted medium brown sand. Depth = 0.150†
91	D	36x13	95% coverage of a moderately well sorted fine grey sand overlying well sorted medium brown sand. Depth = 0.150†
92	D	8x2	Very fine grey sand (10 mm) overlies a medium brown sand (20 mm) which overlies a coarse to medium brown sand (30 mm).
93	D	20x3	Very fine grey sand overlying medium brown sand. Depth = 0.150
94	D	4x1	Minor very fine grey sand overlying medium brown sand. Depth = 0.100
95	D	23x5	98% coverage of very fine grey sand overlying medium brown sand. Depth = 0.150
96	D	4x1	1 mm very fine grey sand overlying grey/brown medium sand. Depth = 0.050
97	D	12x5	15 mm of well sorted fine to very fine grey sand overlying well sorted fine brown sand. Depth = 0.120†
98	D	28x4	3 mm of fine brown sand overlying moderately well sorted medium to fine brown sand. Depth = 0.100†
99	D	15x2	Brown/grey medium to fine sand. Depth = 0.120
100	D	4x2	Very fine grey sand overlying medium grey sand. Depth = 0.080
101	D	19x1	Moderately sorted medium grey sand. Depth = 0.150†
102	D	12x1	Moderately sorted medium to fine brown/grey sand. Depth = 0.100†
103	D	42x1	Moderately sorted medium brown/grey sand with very fine grey sand towards the ends. Depth = 0.100†
104	D	13x2	Moderately well sorted medium to fine grey sand at the southern end and moderately well sorted fine grey sand at the northern end. Depth = 0.100†
W1	F	12 m long	Grey well sorted fine sand.†
W2	F	11 m long	Grey moderately well sorted medium to fine sand.†
W3	F	10 m long	Grey moderately well sorted fine sand.†

NOTES: 1) All sizes are given in metres unless otherwise stated and are maximum dimensions.
2) Hand held lens used to describe soils, sizes are as follows: very coarse sand 1-2 mm; coarse sand 0.5-1 mm; medium sand 0.25-0.5 mm; fine sand 0.125-0.25 mm; very fine sand 0.063-0.125 mm; and coarse silt 0.004-0.063 mm.
† Soil sample(s) retrieved from this boil.
‡ Particle size distribution given in this article.

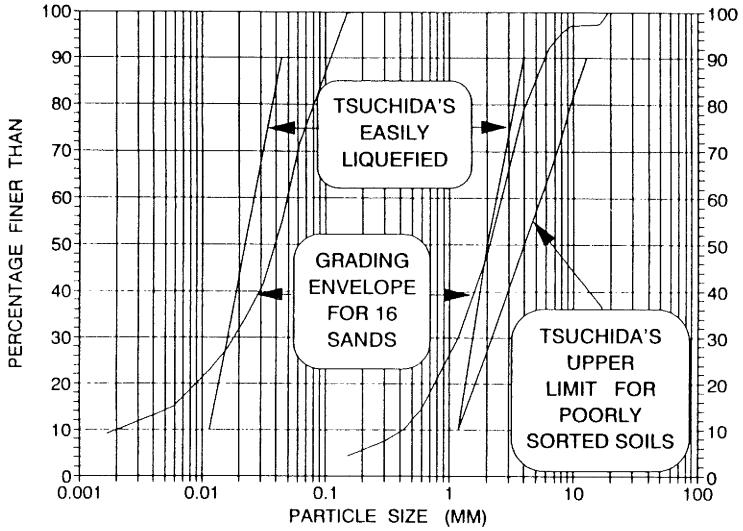

Figure 8 PSD of the Ormond samples compared with Tsuchida's boundaries.

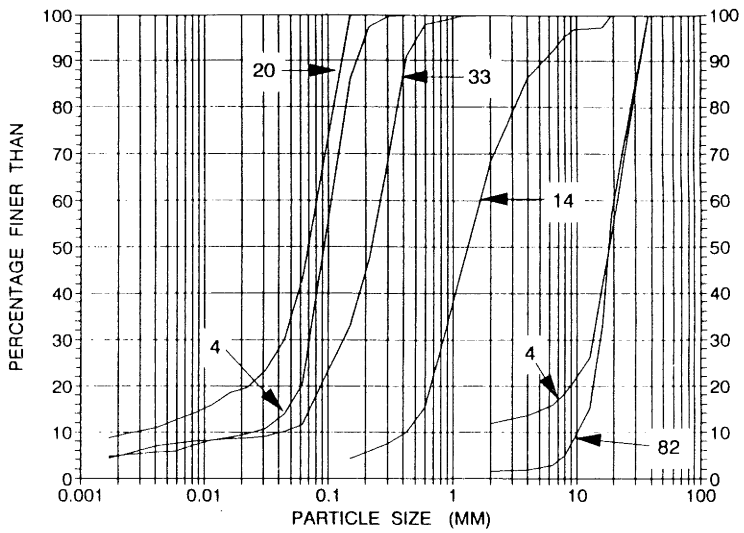

Figure 9 PSD for samples from boils 4(x2), 14, 20, 33 and 82.

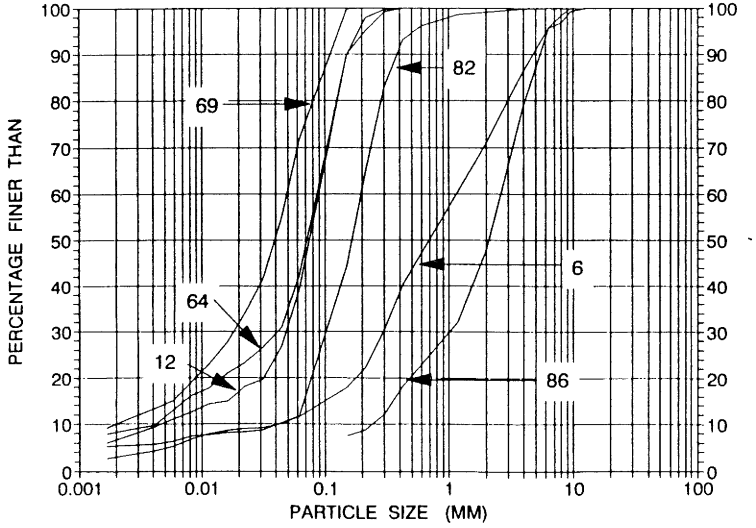

Figure 10 PSD for samples from boils 6, 12, 64, 69, 82 and 86.

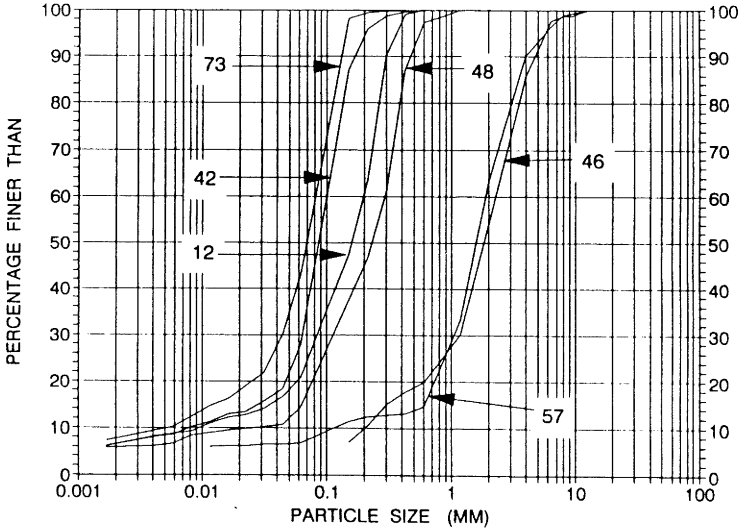

Figure 11 PSD for samples from boils 12, 42, 46, 48, 57 and 73.

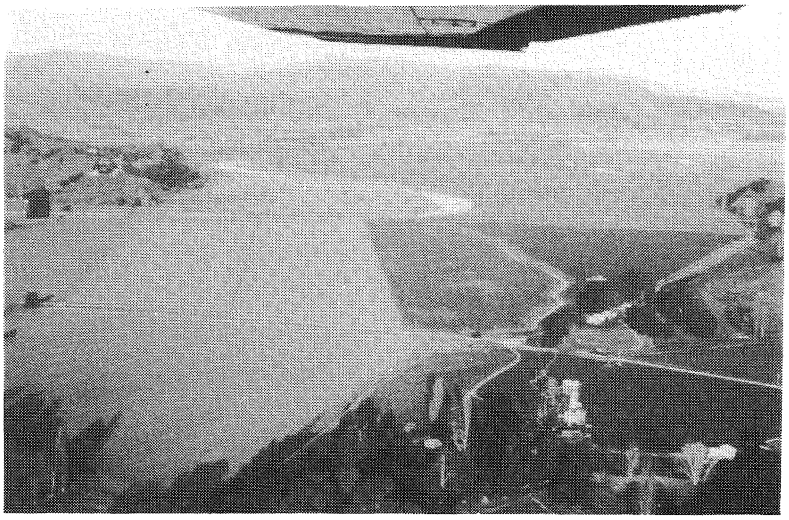

Figure 12 Overview of Site 4 showing line of boils 67-71 in foreground.

Figure 13 Boil #4 in cultivated maze paddock showing extent of gravel lying on top of fine grey sand ejecta.

Figure 14 Closeup of gravel on top of boil #4.

Figure 15 Looking south at boil #14 consisting of a poorly sorted fine gravel.

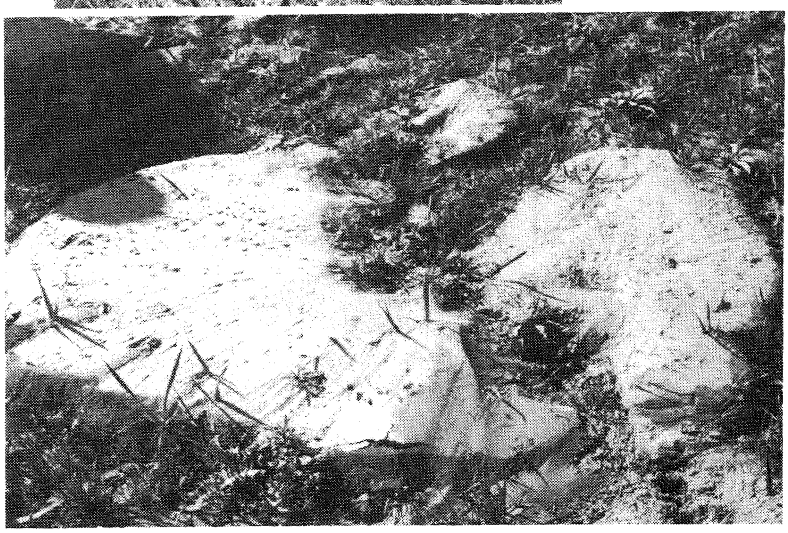

Figure 16 Closeup of boil #14 which is a poorly sorted fine gravel.

Figure 17 Closeup of boil #61 showing coarse grey silt under medium brown sand.

Figure 18 Area of ejected water, producing mounds of topsoil (boil #56).

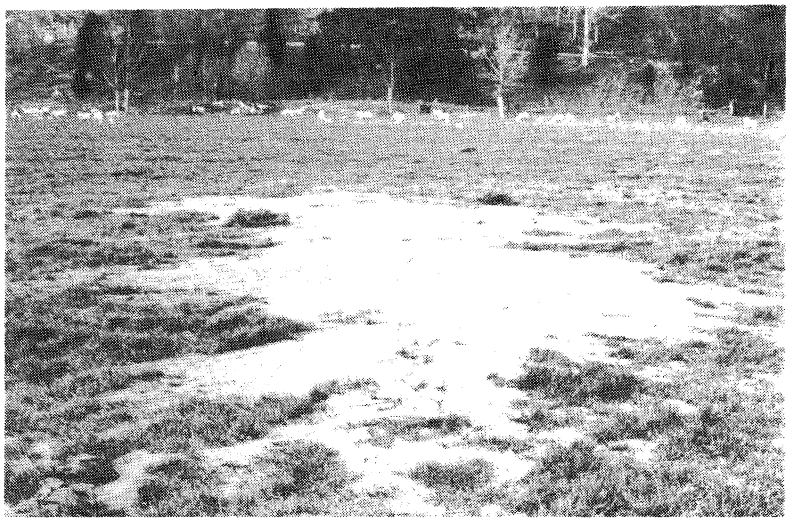

Figure 19 Typical boil (#30) of medium sand, with thin layer of fine sand on top, looking towards the east.

Figure 20 Closeup of central left lobe of boil #30 showing ejected organics.

Figure 21 Aerial view of Site 4 looking west, showing typical boils.

Figure 22 Aerial view of Site 2 looking in SE direction showing a long linear boil (#21).

Figure 23 Looking south at a typical boil (#40) consisting of a medium grey sand at Site 3.

Figure 24 Boil #90 looking east. Boil is covered with medium brown sand in the foreground and fine grey sand in background.

Figure 25 Closeup looking east at a typical fine grey sand boil (#73) at Site 5.

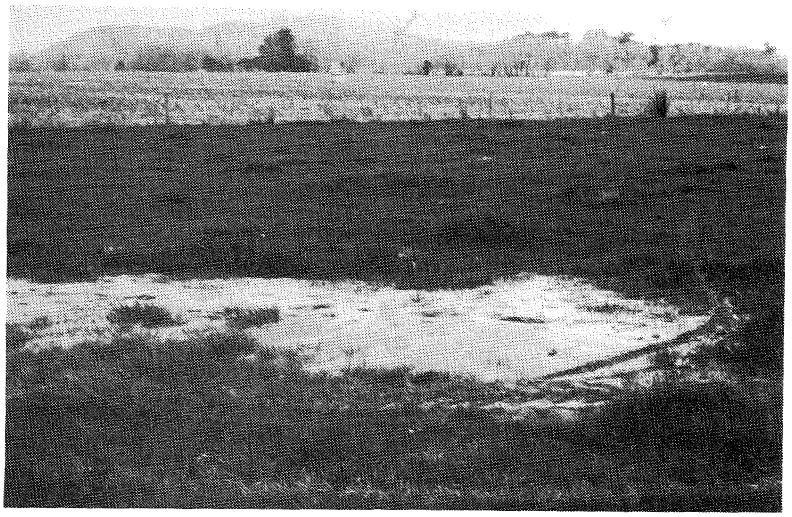

Figure 26 Closeup looking SE at a typical medium grey sand boil (#1) at Site 1.

CONCLUSIONS

The Ormond Earthquake should provide an interesting testing ground for liquefaction research in the future, due to the varied nature of ejected sediments produced from a earthquake with relatively low intensity.

Another interesting factor is the very deep water tables at Site 4, and possibly other sites, indicating that the soils have been ejected from substantial depths under high confining pressures.

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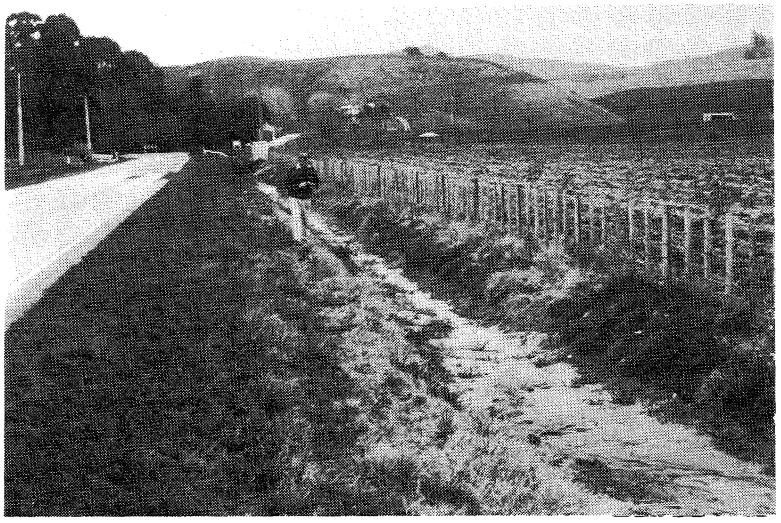

Figure 27 Boils (#101 and #103) in drain beside the road at Site 4.