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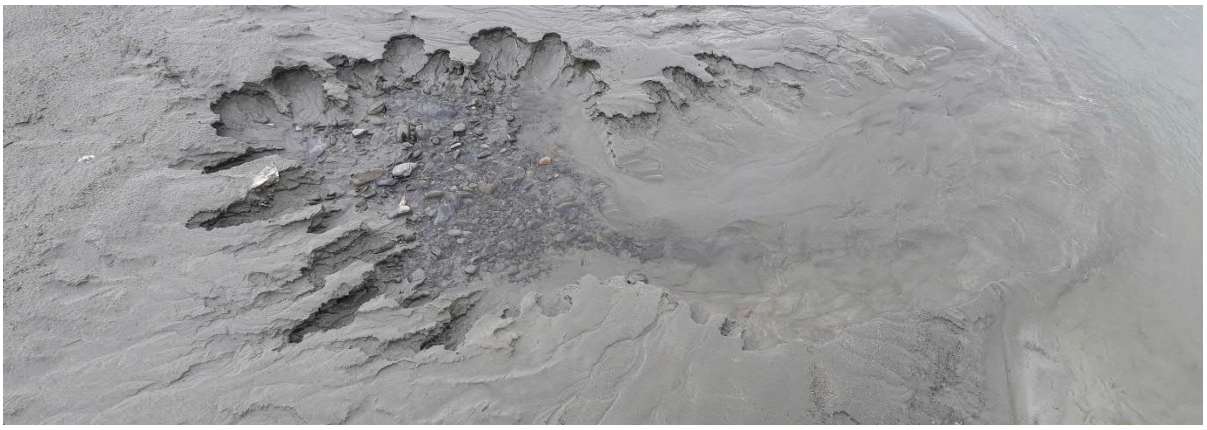
The Hydrogeology of the Pourewa Sub-Catchment, Rangitikei, New Zealand

A thesis presented in partial fulfilment of the requirements for the degree of
Doctor of Philosophy in Earth Science
at Massey University, Palmerston North, New Zealand.

Callum Rees

2020

Volume 2
(Appendices)



"All water has a perfect memory and is forever trying to get back to where it was."

- Toni Morrison

A spring emerging from Kakariki Terrace gravels. This represents an unconfined productive Late Quaternary gravel aquifer that is susceptible to pollution. Note distinctive groundwater sapping.

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Appendices

Overview

This thesis has been split into two volumes for practicality and printing purposes. The following volume carries on from the first, including ongoing page numbers. As such, it can be referenced as a single body of work. The appendices contain supplementary information relevant to Volume 1. The datasets are ordered by their constituent chapter to create a clear reference to Volume 1.

Supplementary datasets cover the following key aspects:

- Lithostratigraphy
- Biostratigraphy
- Tephrostratigraphy

The new 1:25 000 geological map series of the central Rangitikei is presented as a series of fold out sheets at the end of this volume. For more information regarding the map sheets, please feel free to contact the author at callumjrees@gmail.com

View east across the Rangitikei Valley near Ohingaiti, keen eyes may just make out the slightest line indicating Hautawa Shellbed cropping out on the browned off grass covered bluff in the middle foreground.

Appendix A

Supplementary data

Appendix A contains supplementary data for the following chapters:

- Chapter 3:
  - Supplementary Data File 3A – stratigraphic nomenclature
- Chapter 4:
  - Supplementary Data File 4A – EPMA data
- Chapter 5:
  - Supplementary Data File 5A – EPMA data
  - Supplementary Data File 5B – Macrofossil data
  - Supplementary Data File 5C – Grain size data
- Chapter 7:
  - Supplementary Data File 7A – Sampling locations
- Statement of Contribution for Chapters 3-8

View east across the Rangitikei Valley, taken from a hilltop near Watershed Road, Mangaonoho. Ohingaiti Sandstone can be seen exposed in the river cliffs.

Supplementary Data File 3A: Historical and new stratigraphic nomenclature proposed for the central Rangitikei

Superior Oil Company NZ (1943)		Fleming (1953) Whanganui		Te Punga (1952) Rangitikei		Potter (1984) Bussell (1984) Rangitikei		This study Rangitikei	
RECENT		POUAKAI GROUP	Papaiti Alluvium St Johns Alluvium Rapanui Frm. Brunswick Frm. Kaiatea Frm	UPPER RANGITIKEI FORMATION	Mangaone Sandstone Halcombe Conglomerate Waituna Conglomerate	POUAKAI GROUP	Westoe Frm. Halcombe Conglomerate Frm.	POUAKAI GROUP	Westoe Frm. Halcombe Conglomerate Frm.
		SHAKESPEARE GROUP	Landguard Frm Putiki Shellbed Mosstown Sand Karaka Siltstone Upper Castlecliff Shellbed Shakespeare Cliff Sand Shakespeare Cliff SIltstone Tainui Shellbed Pinnacle Sand Lower Castlecliff Shellbed Seafield Sand		Rangitawa Fossil Beds Kakariki Conglomerate Ruamahanga Conglomerate Onepuhi Fossil Beds Toms Conglomerate	SHAKESPEARE GROUP	*Mingaroa Fossil Bed Mb.* *Upper Kakariki Shell Conglomerate Mb.* *Te Hiri Shellbed Mb.* *Rangitawa Fossil Bed Mb.* Mangatapu Frm *Kakariki Conglomerate Mb.* *Pryce Shellbed Mb.* *Ruamahanga Conglomerate Mb.* *Otapatu Shellbed Mb.* *Onepuhi Fossil Beds Mb.* Tokorangi Frm *Toms Shellbeds Mb.* *Toms Conglomerate Mb.*	SHAKESPEARE GROUP	*Mangatapu Frm.* *Ruamahanga Conglomerate Mb.* *Tokorangi Frm.* *Toms Conglomerate Mb.*
OTAKI									
CASTLECLIFFIAN	Kimbolton Ash	KAI IWI GROUP	Upper Kai Iwi Siltstone Kupe Frm Upper Westmere Siltstone Lower Westmere Siltstone Omapu Shellbed Lower Kai Iwi Siltstone Kaimatira Pumice Sand		Shell Creek Fossil Beds Waitapu Shell Conglomerate Potaka Pumice		*Shell Creek Fossil Bed Mb.* Reu Reu Frm. Waiomio Frm. (Abbott 1992)	KAI IWI GROUP	Reu Reu Frm. *Waiomio Shellbed Mb.* Waiomio Frm. *Waitapu Shell Conglomerate Mb.* Kaimatira Pumice Sand Frm. *Potaka Pumice Mb.*
	Coutts Creek Horizon	OKEHU GROUP	Upper Okehu Siltstone Okehu Shell Grit Lower Okehu Siltstone Butlers Shell Conglomerate Makirikiri Tuff		Mangapipi Fossil Beds Pakihikura Pumice		Undifferentiated	OKEHU GROUP	*Rewa Frm.* *Mangapipi Conglomerate Mb.* *Mangapipi Mb.* Makirikiri Tuff Frm *Pakihikura Mb.*
	Basal Ash	MAXWELL GROUP	Upper Maxwell Frm Mangahou Siltstone Middle Maxwell Frm Pukekiwi Shell Sand Lower Maxwell Frm Tewkesbury Frm					MAXWELL GROUP	Upper Maxwell Frm Rataiti Frm
NUKUMARUAN	Waipuru Shellbed Mangamako Shellbed Ohingaiti Sand	NUKUMARU GROUP	Waipuru Shellbed Mangamako Shellbed Ohingaiti Sand	MIDDLE RANGITIKEI FORMATION	Waipuru Fossil Beds Mangamako Fossil Beds Ohingaiti Sandstone	RANGITIKEI GROUP	Vinegar Hill Frm *Waipuru Shellbed Mb.* Mangaonoho Frm *Mangamako Shellbed Mb.* Orangipongo Frm *Ohingaiti Sand Mb.*	RANGITIKEI GROUP	Vinegar Hill Frm *Waipuru Shellbed Mb.* Mangaonoho Frm *Mangamako Shellbed Mb.* Orangipongo Frm *Ohingaiti Sand Mb.*
	Tuha Sand Hautawa Shellbed Basal Sand	OKIWA GROUP	Kuranui Limestone Hautawa Shellbed Te Rama Shellbed Parihauhau Shellbed Te Rimu Sand		Tuha Sandstone Basal Sandstone		Makohine Frm *Tuha Sand Mb.* Tikapu Frm *Hautawa Shellbed Mb.* Mangarere Frm. *Te Rimu Sand Mb.*		Makohine Frm *Tuha Sand Mb.* Tikapu Frm *Hautawa Shellbed Mb.* Mangarere Frm. *Te Rimu Sand Mb.*
WAITOTARAN	Mangamahu Concretions Mangaweka Mudstone Frm.	PAPARANGI GROUP	Wilkies Shellbed Makokako Sand Mangaweka Mudstone Paparangi Sandstone	LOWER RANGITIKEI	Mangaweka Concretionary Mudstone	PAPARANGI GROUP	Mangaweka Mudstone (Journeaux et al. 1996)	PAPARANGI GROUP	Mangaweka Mudstone

(Naish & Kamp, 1995)

Supplementary Data File 4A - Normalised EPMA data from the central Rangitikei

Sample code	Tephra-fall/ volcaniclastic unit	Grid Ref.	Reading	SiO2	Al2O3	TiO2	FeO	MgO	CaO	Na2O	K2O	Cl	Total	Water
CR-61	Onepuhi	BL35 302 620	1	77.82833	12.6035	0.138116	1.063786	0.116544	0.722997	3.339782	3.955426	0.231515	100	3.772793
			2	77.67985	12.41205	0.047674	1.01993	0.075286	0.679273	3.56578	4.299172	0.220982	100	3.033922
			3	77.61818	12.48867	0.113313	1.067007	0.077527	0.730464	3.630323	4.06302	0.211497	100	3.107759
			4	77.71304	12.38241	0.011977	0.938296	0.059209	0.612525	3.474382	4.582568	0.225592	100	3.507923
			5	77.45976	12.55405	0.15641	1.206858	0.104637	0.740685	3.353408	4.196688	0.227503	100	3.944426
			6	77.82526	12.5408	0.180954	0.952521	0.087246	0.759097	3.269097	4.153358	0.231659	100	4.199671
			7	77.66462	12.59875	0.227362	0.934292	0.07997	0.734758	3.521339	4.01176	0.227152	100	3.421767
			8	77.7776	12.44867	0.0479	0.995176	0.029599	0.638333	3.472672	4.371548	0.218504	100	3.490665
			9	76.4153	13.6725	0.058679	1.024989	0.085949	0.701359	3.326094	4.353438	0.361693	100	11.37078
			10	77.55916	12.64843	0.047978	0.995747	0.094433	0.733602	3.543801	4.153568	0.223274	100	3.648405
			11	77.53345	12.64571	0.150793	0.868433	0.053009	0.761022	3.400696	4.347239	0.239645	100	4.198482
			12	77.4043	12.63687	0.173314	1.069249	0.111611	0.757868	3.485779	4.141145	0.219856	100	3.310867
			13	77.87239	12.42593	0.174071	0.929882	0.048356	0.571605	3.309959	4.457586	0.210217	100	3.731308
			14	77.61142	12.40649	0.029806	0.983435	0.040383	0.582962	3.686152	4.438305	0.221051	100	3.064192
			15	77.70984	12.57266	0.077927	1.005838	0.071339	0.77745	3.439593	4.144249	0.201113	100	3.60138
			16	77.94782	12.3383	0.089883	1.014992	0.074605	0.575433	3.490668	4.25315	0.215149	100	3.566725
			17	77.62923	12.52275	0.023977	1.058693	0.091092	0.73899	3.643364	4.049339	0.242564	100	3.598818
			18	77.73273	12.44846	0	0.942616	0.060176	0.602593	3.559334	4.426335	0.227748	100	3.301197
			19	77.95233	12.53134	0.023861	0.973572	0.053516	0.613	3.652831	3.98099	0.218566	100	3.129386
			20	77.66912	12.62935	0.144151	1.057647	0.083577	0.7607	3.392904	4.046013	0.216538	100	3.792612
			21	77.67457	12.65011	0.161531	1.066146	0.099679	0.729888	3.251143	4.137165	0.22977	100	3.412041
			22	79.03085	12.62486	0.01205	0.933346	0.058464	0.589189	2.087388	4.444873	0.218979	100	4.088585
			Av	77.69587	12.58103	0.095079	1.004657	0.075282	0.686991	3.404386	4.227588	0.229117	100	3.922441
			StD	0.417302	0.256404	0.066971	0.070533	0.022597	0.07113	0.313017	0.175099	0.030365		1.659576

Sample code	Tephra-fall/ volcaniclastic unit	Grid Ref.	Reading	SiO2	Al2O3	TiO2	FeO	MgO	CaO	Na2O	K2O	Cl	Total	Water
CR-62B	Kupe	BL34 109 672	1	77.57578	12.36915	0.187634	1.269802	0.104171	0.733588	3.621679	3.911081	0.227118	100	4.530542
			2	77.39177	12.33033	0.197598	1.302677	0.104151	0.777562	3.765812	3.90454	0.225565	100	3.496095
			3	77.74902	12.35282	0.273756	1.309531	0.077968	0.761699	3.498467	3.73325	0.243491	100	5.013353
			4	77.86112	12.38253	0.212531	1.229988	0.077825	0.704813	3.8311	3.461517	0.238577	100	4.838929
			5	77.56285	12.37617	0.188113	1.364051	0.112214	0.772428	3.678381	3.715416	0.230377	100	4.773645
			6	77.8242	12.32773	0.23797	1.16167	0.0715	0.651496	3.493461	3.984151	0.247815	100	5.298403
			7	78.21417	12.26858	0.115368	1.072429	0.047804	0.579199	3.507316	3.946748	0.248392	100	4.833491
			8	77.8791	12.33865	0.206476	1.011501	0.067825	0.552992	3.550875	4.176321	0.216256	100	4.846638
			9	77.92012	12.31083	0.211028	1.338308	0.105977	0.699826	3.553976	3.631929	0.228016	100	4.160814
			10	77.44012	12.39541	0.119359	1.33415	0.088507	0.752973	3.801057	3.848004	0.220424	100	3.174377
			Average	77.74182	12.34522	0.194983	1.239411	0.085794	0.698657	3.630212	3.831296	0.232603	100	4.496629
			Std	0.238324	0.036231	0.045734	0.114058	0.019704	0.075871	0.123932	0.191643	0.010752		0.648311

Sample code	Tephra-fall/ volcaniclastic unit	Grid Ref.	Reading	SiO2	TiO2	Al2O3	FeO	MgO	CaO	Na2O	K2O	Cl	Total	Water
CR-47	Kaukatea	BL35 320 647	1	75.87601	0.319459	13.05355	1.796105	0.137257	1.083915	4.179012	3.370348	0.184345	100	4.827888
			2	76.41406	0.207772	13.28476	1.576023	0.159505	1.087015	3.852262	3.249015	0.169587	100	5.654804
			3	76.68233	0.295782	13.01617	1.419456	0.111485	0.912078	3.654958	3.75973	0.148017	100	5.324795
			4	75.93063	0.168211	13.23047	1.712328	0.160387	1.088627	4.054001	3.467438	0.187907	100	4.870055
			5	76.43733	0.200569	13.38578	1.602016	0.132658	1.106864	3.696944	3.262456	0.175382	100	6.255581
			6	75.98154	0.188727	13.31973	1.646281	0.166528	1.07831	4.022931	3.41665	0.179303	100	4.613205
			7	76.02622	0.252456	13.26912	1.634925	0.147286	1.134747	3.830462	3.530698	0.174084	100	4.922699
			8	78.06531	0.123861	12.8864	1.643684	0.139466	0.917625	2.399085	3.652562	0.171998	100	6.335771

			Av		76.42668	0.219605	13.18075	1.628852	0.144322	1.051147	3.711207	3.463612	0.173828	100	5.3506
			Std		0.676256	0.061357	0.162926	0.101772	0.016876	0.08044	0.52353	0.167825	0.01134		0.623875
CR-31	Potaka	BL34 052 739	Reading		SiO2	Al2O3	TiO2	FeO	MgO	CaO	Na2O	K2O	Cl	Total	Water
				1	77.87167	12.62914	0	1.007935	0.054653	0.661096	3.296022	4.240895	0.238583	100	4.855
				2	78.15376	12.49067	0.027983	1.139002	0.110895	0.810463	3.20558	3.805655	0.25599	100	3.512
				3	77.8461	12.6089	0	1.276627	0.109425	0.886865	2.999291	4.018508	0.254283	100	4.044
				4	78.44787	12.4314	0	0.876873	0.093728	0.74253	3.058642	4.114639	0.234319	100	3.977
				5	77.93401	12.56354	0.014463	1.210794	0.102277	0.866771	3.125129	3.959874	0.22315	100	3.204
			Av		78.05068	12.54473	0.008489	1.102246	0.094196	0.793545	3.136933	4.027914	0.241265	100	3.9184
			Std		0.22623	0.073979	0.011242	0.143687	0.020688	0.083069	0.105105	0.146287	0.012409		0.560706
CR-32	Potaka	BL34 049 741	Reading		SiO2	Al2O3	TiO2	FeO	MgO	CaO	Na2O	K2O	Cl	Total	Water
				1	77.95489	12.68505	0.007434	1.284965	0.098762	0.868679	3.40144	3.442856	0.255931	100	5.834
				2	77.54064	12.9057	0.003193	1.29866	0.129866	0.968672	3.551089	3.370129	0.232056	100	6.057
				3	78.00724	12.631	0	0.992769	0.084943	0.637071	3.463544	3.949841	0.233593	100	5.819
				4	77.49728	12.81173	0.0074	1.308765	0.144831	0.866872	3.579546	3.570032	0.213546	100	5.407
				5	77.86321	12.81967	0.02124	1.196899	0.08921	0.869796	3.330501	3.562022	0.247451	100	5.84
				6	77.99633	12.58147	0	0.935188	0.095513	0.755707	3.008134	4.377854	0.249803	100	4.725
				7	78.03421	12.59991	0	1.052988	0.081406	0.690362	3.054299	4.244724	0.242103	100	5.412
				8	77.75399	12.62245	0.010345	1.040665	0.09517	0.716879	3.464399	4.042661	0.253442	100	3.331
				9	77.78781	12.6396	0.010379	1.031677	0.06435	0.723419	3.410553	4.078964	0.253249	100	3.652
				10	78.36202	12.45242	0	1.128182	0.103912	0.872645	3.281696	3.556319	0.242814	100	5.689
				11	77.96367	12.61224	0.002064	0.998039	0.084632	0.701827	3.377025	4.015894	0.244607	100	3.11
				12	77.80608	12.61093	0	1.061439	0.121159	0.689677	3.096296	4.380378	0.234034	100	3.433
				13	78.01492	12.58638	0	1.028148	0.099022	0.661554	3.357281	4.004087	0.248609	100	5.072
				14	77.48972	12.79862	0.006232	1.207985	0.126719	0.871453	3.391292	3.88882	0.219162	100	3.724
				15	78.01407	12.63369	0	0.989429	0.059303	0.655458	3.230472	4.177244	0.240335	100	3.884
				16	77.60983	12.58855	0	1.166166	0.135238	0.886327	3.33205	4.043609	0.238227	100	3.873
				17	77.93605	12.459	0.009283	1.076844	0.114492	0.868489	3.216091	4.082517	0.237236	100	3.05
				18	77.72774	12.47876	0.016679	1.219627	0.12092	0.874587	2.87811	4.454243	0.229331	100	4.069
				19	79.41833	12.79081	0	1.044191	0.066196	0.687586	1.785161	3.962161	0.245566	100	6.339
				20	78.02539	12.54746	0.011568	1.25464	0.121994	0.835025	3.375856	3.577776	0.250297	100	4.913
				21	78.15925	12.53901	0	1.107856	0.113981	0.720107	3.174434	3.900932	0.284421	100	6.125
				22	77.94481	12.78425	0.006361	0.960489	0.087992	0.720896	3.43804	3.801669	0.255494	100	5.673
				23	77.43042	12.74996	0.020231	1.302255	0.124582	1.019017	3.619269	3.510659	0.223609	100	6.086
				24	77.58191	12.76841	0.018009	1.274405	0.151488	0.996854	3.497993	3.475746	0.235177	100	5.603
			Av		77.91332	12.65405	0.006267	1.123428	0.10482	0.79829	3.263107	3.894631	0.242087	100	4.863333
			StD		0.387951	0.121151	0.006948	0.119263	0.024605	0.111603	0.356956	0.314537	0.01415		1.082766
CR-52	Rewa	BL34 053 753	Reading		SiO2	Al2O3	TiO2	FeO	MgO	CaO	Na2O	K2O	Cl	Total	Water
				1	76.03268	13.00004	0.248941	2.011802	0.119795	1.003587	4.061438	3.328254	0.193467	100	5.326814
				2	74.5682	13.52125	0.356266	2.284553	0.276189	1.423586	4.176983	3.171283	0.221682	100	4.905185
				3	75.46465	13.1279	0.283023	1.994843	0.135116	1.059222	4.154255	3.569961	0.211029	100	5.017438
				4	74.92802	13.37945	0.281235	2.168644	0.24436	1.279581	4.325325	3.209119	0.184273	100	3.104096
				5	73.757	13.57745	0.396106	2.533361	0.434158	1.635526	4.256409	3.225898	0.184094	100	2.384076
				6	75.87274	12.98214	0.160504	1.92833	0.117695	1.022283	4.323146	3.388747	0.204421	100	3.637739
				7	75.78579	12.99532	0.23505	1.944543	0.113686	1.051184	4.356403	3.328267	0.18975	100	2.865456
				8	75.71836	12.96106	0.212864	2.08027	0.119121	0.991053	4.348698	3.37476	0.193819	100	3.121348
				9	75.80948	13.05546	0.18223	2.068527	0.107692	0.981587	4.065656	3.55479	0.174577	100	3.001435

				10	74.26027	13.69821	0.481114	2.433887	0.38577	1.469231	3.87924	3.191209	0.20107	100	4.323492
				11	75.45515	13.25087	0.269197	2.182863	0.120868	1.176782	4.006253	3.331642	0.206374	100	2.874947
				12	75.82418	13.03123	0.232483	1.980404	0.102962	1.041235	3.953405	3.642153	0.191946	100	3.376682
				13	75.20614	13.50631	0.310292	2.336094	0.16032	1.26907	4.089102	2.945534	0.177144	100	5.056971
				14	75.24111	13.60818	0.256631	2.043458	0.170175	1.238489	4.189508	3.082155	0.170289	100	5.294007
				15	75.7874	13.17601	0.261466	1.886676	0.128989	1.045551	4.290147	3.235288	0.188476	100	2.819963
				16	75.68392	12.99984	0.20468	2.045884	0.090112	1.053028	4.278892	3.444441	0.199197	100	2.845813
				17	75.28889	13.0832	0.292702	2.123424	0.12991	0.974495	3.876266	3.809929	0.421189	100	11.93266
				18	74.82662	13.45127	0.262156	2.187387	0.270976	1.349301	4.324062	3.144018	0.184219	100	3.075797
				19	70.46014	17.17023	0.11185	1.469018	0.067485	2.941483	5.390475	2.279693	0.109631	100	1.228995
				Av	75.05109	13.45134	0.265199	2.089682	0.173441	1.263488	4.228719	3.276692	0.20035	100	4.010154
				Std	1.232578	0.909308	0.081283	0.222988	0.099051	0.437021	0.313742	0.310034	0.056628		2.163689
CR-66	Potaka	BL35 330 646		Reading	SiO2	Al2O3	TiO2	FeO	MgO	CaO	Na2O	K2O	Cl	Total	Water
				1	77.79919	12.69608	0	1.040312	0.098736	0.728138	3.367339	4.055064	0.215137	100	3.561574
				2	77.19971	12.82238	0.150091	1.247856	0.101128	0.973076	3.582494	3.698868	0.224394	100	3.750321
				3	77.7301	12.57295	0.065736	0.921559	0.083155	0.76644	3.568147	4.076476	0.215445	100	3.30441
				4	77.85015	12.62071	0.077762	1.027979	0.048188	0.661684	3.302838	4.185359	0.225332	100	3.396466
				5	77.6511	12.47937	0.029817	1.071139	0.10045	0.740928	3.555224	4.12802	0.24395	100	3.100736
				6	77.38975	12.52347	0.142051	1.311676	0.096448	0.868229	3.406989	4.043649	0.217738	100	2.370401
				7	77.57323	12.51792	0.263289	1.144492	0.132566	0.874892	3.449871	3.821856	0.221892	100	3.431618
				8	77.82374	12.53628	0.178264	0.991831	0.099004	0.730665	3.448526	3.980081	0.211602	100	2.753996
				9	77.64086	12.57747	0.036047	1.055785	0.104497	0.707913	3.607889	4.039692	0.229851	100	3.816101
				10	77.98743	12.40491	0.029898	0.928451	0.055836	0.742941	3.488757	4.133	0.228774	100	3.363285
				11	77.927	12.40347	0.197807	1.076664	0.073531	0.83508	3.281397	4.006591	0.19846	100	3.597966
				12	78.01833	12.54859	0.071507	0.997784	0.048005	0.647703	3.435497	4.015129	0.21746	100	3.02759
				13	78.02957	12.43586	0.101459	0.965644	0.098346	0.841989	3.371391	3.935305	0.220434	100	3.178703
				14	77.33852	12.69405	0.166598	1.06872	0.079525	0.762148	3.62619	4.040108	0.224137	100	2.881402
				15	77.92472	12.4371	0.077871	1.085436	0.089932	0.724071	3.405514	4.028822	0.226529	100	3.531668
				16	77.94687	12.37108	0.053752	1.145469	0.104976	0.819603	3.356389	3.984789	0.217074	100	3.24694
				17	77.68828	12.43317	0.101403	1.186126	0.088462	0.686606	3.461734	4.143567	0.210657	100	3.125009
				18	77.62835	12.41733	0.239282	1.328859	0.097478	0.865999	3.288906	3.904922	0.228868	100	3.402659
				19	77.54204	12.46818	0.190178	1.300278	0.103372	0.869884	3.494461	3.816474	0.215133	100	2.769156
				20	77.50066	12.49964	0.189957	1.121757	0.066299	0.700428	3.632909	4.04726	0.241088	100	2.656017
				21	77.89376	12.56904	0.095618	0.943724	0.068933	0.683106	3.407373	4.109808	0.22864	100	3.306692
				22	77.32074	12.42638	0.144445	1.293428	0.125622	0.900229	3.585907	3.997782	0.205466	100	3.988456
				23	77.43235	12.69254	0.214437	1.069916	0.100335	0.736262	3.463414	4.077756	0.212993	100	2.989956
				24	77.54951	12.56574	0.132147	1.024863	0.057188	0.664454	3.572295	4.210185	0.223624	100	3.799132
				Av	77.68275	12.52974	0.122892	1.097906	0.088417	0.772186	3.465061	4.020023	0.221028	100	3.264594
				StD	0.23645	0.111172	0.070498	0.12147	0.02188	0.08637	0.105566	0.117077	0.010031		0.392984
CR-53	Rewa	BL34 053 757		Reading	SiO2	Al2O3	TiO2	FeO	MgO	CaO	Na2O	K2O	Cl	Total	Water
				1	75.23546	13.47028	0.340324	2.11132	0.183593	1.206161	4.215501	3.028096	0.209258	100	4.915436
				2	75.30544	13.39384	0.346249	2.16077	0.130127	1.133567	4.1319	3.204131	0.19397	100	4.873757
				3	75.3159	13.46094	0.346161	2.188078	0.172347	1.228691	4.151829	2.927838	0.208219	100	4.849432
				4	75.06887	13.42722	0.380915	2.15711	0.152769	1.18354	4.252314	3.179754	0.197516	100	4.428731
				5	75.50782	13.54105	0.220209	2.111081	0.131035	1.171872	4.244149	2.875655	0.197123	100	5.532499
				6	75.87175	13.22794	0.135056	2.108928	0.118018	1.179041	3.974715	3.174069	0.210479	100	5.87119
				7	75.05855	13.53351	0.380367	2.427977	0.152763	1.226473	4.11162	2.918258	0.190483	100	5.810372
				8	74.97031	13.39594	0.311208	2.265054	0.126013	1.125448	4.200355	3.413683	0.191984	100	3.446664

				9	75.38125	13.31572	0.296936	2.042226	0.118719	1.199813	4.115331	3.313314	0.216688	100	4.643987
			Av		75.30171	13.41849	0.30638	2.174727	0.14282	1.183845	4.155302	3.114977	0.201747	100	4.93023
			StD		0.258527	0.094749	0.07619	0.106945	0.022387	0.034458	0.081402	0.177245	0.008943		0.712361
CR-54	Ridge	BL34 068 763	Reading		SiO2	Al2O3	TiO2	FeO	MgO	CaO	Na2O	K2O	Cl	Total	Water
				1	75.6954	13.06843	0.244233	2.060066	0.090525	0.943536	4.32923	3.385372	0.183202	100	2.995183
				2	75.26125	13.47603	0.257911	2.153976	0.160777	1.177421	4.142299	3.211295	0.159036	100	5.89906
				3	70.52849	17.74198	0	1.026528	0.047318	2.783679	5.371437	2.373215	0.127355	100	3.855778
				4	75.50724	13.10547	0.327875	2.10368	0.145166	0.938507	4.461487	3.232494	0.178075	100.0	3.06765
				5	75.85621	13.08161	0.281033	1.911229	0.109621	0.928514	4.493402	3.151385	0.186993	100	5.416711
				6	75.79956	13.19757	0.285047	1.924311	0.136147	0.965617	3.875741	3.621786	0.194223	100	6.748471
				7	76.39181	13.19914	0.185417	1.909493	0.116556	0.942299	3.976947	3.106445	0.17189	100	6.505393
				8	74.37258	13.67487	0.487983	2.432358	0.16864	1.279096	4.456366	2.944996	0.183108	100	5.267399
				9	75.89287	13.23213	0.220567	1.875604	0.113299	0.959649	4.266652	3.267925	0.171298	100	5.685879
				10	75.73423	13.21788	0.267764	1.839338	0.106965	0.952204	4.387305	3.312526	0.181785	100	5.045761
				11	75.58538	13.09599	0.2922	2.152748	0.109182	0.945497	4.339264	3.288448	0.191294	100	3.098396
				12	75.80423	13.14418	0.292994	1.973087	0.119583	0.949224	4.213012	3.332132	0.171558	100	5.333213
				13	75.70538	12.90812	0.257633	2.166104	0.099826	0.950931	4.232303	3.506017	0.173685	100	3.554712
				14	74.70328	13.54599	0.232854	2.19122	0.099478	1.073969	4.486866	3.484471	0.181866	100	3.217751
				15	74.72047	13.51802	0.300078	2.28306	0.109884	1.06703	4.414076	3.41075	0.176627	100	3.716953
				16	75.77459	12.98782	0.211014	2.123278	0.123631	0.945282	4.30374	3.360305	0.170336	100	4.154405
				17	75.61328	13.09133	0.245409	2.084769	0.104112	0.949038	4.319591	3.411032	0.181441	100	3.459935
			Av		75.23213	13.48745	0.258236	2.012403	0.115336	1.103029	4.357042	3.258858	0.175516	100	4.530744
			StD		1.273169	1.083163	0.090657	0.289405	0.026955	0.430762	0.303066	0.270734	0.014628		1.234167
CR-57	Ridge	BL34 083 775	Reading		SiO2	Al2O3	TiO2	FeO	MgO	CaO	Na2O	K2O	Cl	Total	Water
				1	75.47401	13.05677	0.292543	1.973791	0.10596	0.970618	3.728983	4.186767	0.21056	100	9.137825
				2	75.43767	13.13213	0.228612	2.06649	0.134157	0.947272	4.105551	3.781633	0.166476	100	1.421874
				3	75.75068	13.12043	0.243661	1.904244	0.107723	0.924176	4.455278	3.286551	0.207259	100	2.767442
				4	75.48588	13.28726	0.369439	1.95134	0.090552	0.95146	4.35545	3.331498	0.177119	100	3.024175
				5	74.97581	13.22058	0.369639	2.127265	0.150019	0.907659	3.550693	4.474419	0.223916	100	6.203281
				6	75.57796	13.18388	0.240362	1.987977	0.125424	0.958538	4.384611	3.361743	0.1795	100	3.836922
				7	75.97589	12.70935	0.33053	2.071939	0.132038	0.978864	4.064794	3.532315	0.204278	100	3.846274
				8	75.4153	13.17113	0.434716	2.033141	0.106851	0.946099	4.452399	3.275621	0.164741	100	2.964205
				9	75.71653	13.02388	0.305437	2.066922	0.138163	0.93709	4.401535	3.206863	0.203575	100	3.514248
				10	75.73039	13.13392	0.167576	1.880705	0.154504	0.871202	3.943531	3.947318	0.17085	100	3.447921
			Av		75.55401	13.10393	0.298251	2.006381	0.124539	0.939298	4.144283	3.638473	0.190827	100	4.016417
			StD		0.255517	0.149804	0.076269	0.07587	0.019946	0.030077	0.305471	0.417036	0.020215		2.050146
ATHOG-28	n/a	n/a	Reading		SiO2	Al2O3	TiO2	FeO	MgO	CaO	Na2O	K2O	Cl	Total	Water
				1	75.82219	12.28444	0.286557	3.228368	0.085356	1.721344	3.951798	2.583169	0.036776	100	0
				2	75.86066	12.31071	0.279469	3.296508	0.117225	1.730924	3.693083	2.679213	0.032209	100	0
				3	75.74391	12.21425	0.324982	3.202587	0.116729	1.773406	3.807719	2.788695	0.027726	100	0.28362
				4	75.41769	12.47525	0.311287	3.225646	0.112129	1.731306	3.90578	2.781493	0.039414	100	0.628751
				5	75.68087	12.28172	0.316669	3.264393	0.110419	1.774221	3.809736	2.705534	0.056441	100	0
				6	75.59042	12.44679	0.373581	3.124267	0.099926	1.767184	3.81595	2.742545	0.03934	100	0.441332
				7	75.57301	12.17245	0.365186	3.244465	0.100651	1.756365	3.97006	2.778582	0.039233	100	0.169379
				8	75.95084	12.35958	0.373475	3.141242	0.088909	1.747619	3.666446	2.633718	0.038172	100	0.412957
				9	75.90695	12.33548	0.33671	3.158177	0.091953	1.731701	3.723551	2.675413	0.040071	100	-0.61784
				10	75.64529	12.39745	0.217348	3.436938	0.099522	1.712065	3.777521	2.671218	0.042638	100	0.037173

				11	76.05576	12.35809	0.360266	3.132173	0.110373	1.765406	3.456255	2.714036	0.047635	100	0.850421
				12	75.59828	12.27167	0.232032	3.347198	0.084575	1.739659	4.026335	2.65186	0.048389	100	0.014734
				13	75.68687	12.22591	0.370932	3.355096	0.105234	1.706815	3.782227	2.724011	0.042905	100	0
				14	75.87154	12.29844	0.29218	3.363842	0.116057	1.728892	3.644785	2.644525	0.039743	100	0.049842
				15	75.85956	12.25617	0.387499	3.224524	0.075137	1.777858	3.72316	2.645409	0.050686	100	0
				16	76.00161	12.25106	0.277221	3.372125	0.080885	1.683737	3.571558	2.731741	0.030063	100	0.372799
				17	76.25809	12.14364	0.30103	3.235885	0.099398	1.729208	3.481629	2.698804	0.052315	100	0.912648
				18	75.82956	12.27724	0.258914	3.285046	0.087934	1.716982	3.771904	2.729613	0.042811	100	0.439805
				19	75.99098	12.28663	0.374442	3.156917	0.107281	1.773608	3.57616	2.685117	0.048864	100	0.640486
				20	75.65068	12.31978	0.40886	3.239483	0.108901	1.776852	3.672698	2.785155	0.037591	100	0.198808
				21	75.89928	12.43005	0.34887	3.184989	0.090087	1.789649	3.591695	2.636622	0.028758	100	0.23764
			Av		75.80448	12.30461	0.323691	3.248565	0.099461	1.744514	3.734288	2.699356	0.041037	100	0.24155
			StD		0.191284	0.083628	0.051674	0.085638	0.012382	0.0279	0.149958	0.055612	0.007564		0.339822
VG568	n/a	n/a	Reading		SiO2	Al2O3	TiO2	FeO	MgO	CaO	Na2O	K2O	Cl	Total	Water
				1	77.46446	12.24736	0.003709	1.183667	0.040081	0.443769	3.561819	4.969285	0.085859	100	0.715161
				2	77.76256	12.29263	0.007415	0.978219	0.016026	0.412418	3.515271	4.922673	0.092785	100	0.67742
				3	77.72308	12.16533	0.099627	1.183507	0.03788	0.438478	3.626832	4.613298	0.111964	100	0.200667
				4	77.37593	12.21048	0.107615	1.097603	0.028071	0.456071	3.764389	4.855374	0.104475	100	0.764567
				5	77.53305	12.17581	0.037137	1.088475	0.042138	0.425186	3.751812	4.837188	0.109202	100	0.840443
				6	77.78155	12.27942	0.078049	0.946676	0.035142	0.450727	3.497282	4.843957	0.087197	100	0.917871
				7	77.5288	12.20919	0.078131	1.15039	0.045231	0.453221	3.52088	4.905912	0.108238	100	1.022221
				8	77.28503	12.26349	0.132823	1.232902	0.032893	0.443439	3.698866	4.806685	0.103874	100	0.190652
				9	77.61281	12.17047	0.148167	1.157263	0.025018	0.423089	3.627641	4.767172	0.068365	100	0.585089
				10	77.68638	12.25736	0.011098	1.14385	0.041975	0.445626	3.44807	4.866122	0.099522	100	0.456321
				11	77.38829	12.18368	0.018488	1.13337	0.041955	0.450425	3.726723	4.939087	0.117981	100	0.407907
				12	77.24308	12.35327	0.096008	1.119953	0.02893	0.467853	3.729397	4.855237	0.106271	100	0.273807
				13	77.5904	12.31165	0.02425	1.047642	0.017949	0.419936	3.558575	4.940416	0.089184	100	1.019838
				14	77.34064	12.29813	0.104755	1.078376	0.027365	0.462207	3.656082	4.946864	0.085571	100	0.709243
				15	77.68787	12.12566	0.068991	1.020716	0.030744	0.446167	3.559133	4.957736	0.102984	100	1.42545
				16	77.44931	12.20898	0.052172	1.117254	0.022149	0.433738	3.780329	4.829981	0.106083	100	1.182999
				17	77.3035	12.21007	0.055657	1.323545	0.030072	0.448972	3.768369	4.755352	0.104463	100	0.753166
				18	77.39482	12.20014	0.118842	1.135354	0.047156	0.471546	3.740871	4.78555	0.105719	100	0.843112
				19	77.66043	12.16177	0.060513	0.936527	0.038993	0.46889	3.596156	4.953215	0.123514	100	0.836567
				20	77.48395	12.22171	0.044238	1.073405	0.027315	0.440114	3.566711	5.037171	0.105381	100	0.526971
				21	77.65605	12.20607	0.008099	1.00947	0.032794	0.446225	3.578499	4.970078	0.092709	100	1.212796
				22	77.38336	12.22594	0.028099	1.193008	0.05348	0.448387	3.602964	4.967327	0.097435	100	0.342184
				23	77.80371	12.27533	0.036197	0.877748	0.039924	0.438116	3.478877	4.948031	0.102059	100	0.532887
				24	76.98114	12.14419	0.100462	1.785924	0.026244	0.440775	3.524183	4.90508	0.091997	100	0.447863
			Av		77.50501	12.22492	0.063356	1.125619	0.03373	0.444807	3.619989	4.88245	0.100118	100	0.70355
			StD		0.197339	0.056048	0.04195	0.16941	0.009183	0.014721	0.100484	0.091236	0.011625		0.31887

Supplementary Data File 5A

Sample Code	Tephra-fall/volcaniclastic unit	Grid Ref	Reading	SiO2	Al2O3	TiO2	FeO	MgO	CaO	Na2O	K2O	Cl	H2O	n
CR-47	Kaukatea Pumice	BL35 320 647	1	75.88	13.05	0.32	1.80	0.14	1.08	4.18	3.37	0.18	4.83	
			2	76.41	13.28	0.21	1.58	0.16	1.09	3.85	3.25	0.17	5.65	
			3	76.68	13.02	0.30	1.42	0.11	0.91	3.65	3.76	0.15	5.32	
			4	75.93	13.23	0.17	1.71	0.16	1.09	4.05	3.47	0.19	4.87	
			5	76.44	13.39	0.20	1.60	0.13	1.11	3.70	3.26	0.18	6.26	
			6	75.98	13.32	0.19	1.65	0.17	1.08	4.02	3.42	0.18	4.61	
			7	76.03	13.27	0.25	1.63	0.15	1.13	3.83	3.53	0.17	4.92	
			8	78.07	12.89	0.12	1.64	0.14	0.92	2.40	3.65	0.17	6.34	
			Mean	76.43	0.22	13.18	1.63	0.14	1.05	3.71	3.46	0.17	5.35	
			StD	0.68	0.06	0.16	0.10	0.02	0.08	0.52	0.17	0.01	0.62	8
CR-66	Potaka Pumice	BL35 330 646	1	77.80	12.70	0.00	1.04	0.10	0.73	3.37	4.06	0.22	3.56	
			2	77.20	12.82	0.15	1.25	0.10	0.97	3.58	3.70	0.22	3.75	
			3	77.73	12.57	0.07	0.92	0.08	0.77	3.57	4.08	0.22	3.30	
			4	77.85	12.62	0.08	1.03	0.05	0.66	3.30	4.19	0.23	3.40	
			5	77.65	12.48	0.03	1.07	0.10	0.74	3.56	4.13	0.24	3.10	
			6	77.39	12.52	0.14	1.31	0.10	0.87	3.41	4.04	0.22	2.37	
			7	77.57	12.52	0.26	1.14	0.13	0.87	3.45	3.82	0.22	3.43	
			8	77.82	12.54	0.18	0.99	0.10	0.73	3.45	3.98	0.21	2.75	
			9	77.64	12.58	0.04	1.06	0.10	0.71	3.61	4.04	0.23	3.82	
			10	77.99	12.40	0.03	0.93	0.06	0.74	3.49	4.13	0.23	3.36	
			11	77.93	12.40	0.20	1.08	0.07	0.84	3.28	4.01	0.20	3.60	
			12	78.02	12.55	0.07	1.00	0.05	0.65	3.44	4.02	0.22	3.03	
			13	78.03	12.44	0.10	0.97	0.10	0.84	3.37	3.94	0.22	3.18	
			14	77.34	12.69	0.17	1.07	0.08	0.76	3.63	4.04	0.22	2.88	
			15	77.92	12.44	0.08	1.09	0.09	0.72	3.41	4.03	0.23	3.53	
			16	77.95	12.37	0.05	1.15	0.10	0.82	3.36	3.98	0.22	3.25	
			17	77.69	12.43	0.10	1.19	0.09	0.69	3.46	4.14	0.21	3.13	
			18	77.63	12.42	0.24	1.33	0.10	0.87	3.29	3.90	0.23	3.40	
			19	77.54	12.47	0.19	1.30	0.10	0.87	3.49	3.82	0.22	2.77	
			20	77.50	12.50	0.19	1.12	0.07	0.70	3.63	4.05	0.24	2.66	
			21	77.89	12.57	0.10	0.94	0.07	0.68	3.41	4.11	0.23	3.31	
			22	77.32	12.43	0.14	1.29	0.13	0.90	3.59	4.00	0.21	3.99	
			23	77.43	12.69	0.21	1.07	0.10	0.74	3.46	4.08	0.21	2.99	
			24	77.55	12.57	0.13	1.02	0.06	0.66	3.57	4.21	0.22	3.80	
			Mean	77.68	12.53	0.12	1.10	0.09	0.77	3.47	4.02	0.22	3.26	
			StD	0.24	0.11	0.07	0.12	0.02	0.09	0.11	0.12	0.01	0.39	24
CJR-T1	Potaka Pumice	BM35 366 399	1	78.21	12.35	0.14	1.11	0.10	0.96	3.49	3.34	0.29	4.45	
			2	78.61	12.16	0.13	1.02	0.07	0.95	3.51	3.30	0.26	6.35	
			3	78.22	12.35	0.14	1.05	0.09	0.95	3.33	3.60	0.27	2.64	
			4	78.23	12.41	0.11	0.93	0.05	0.83	3.37	3.78	0.30	2.94	
			5	78.16	12.37	0.10	0.99	0.07	0.79	3.47	3.77	0.27	3.71	
			6	78.16	12.32	0.14	1.12	0.11	0.95	3.32	3.60	0.28	3.20	
			7	78.12	12.30	0.11	0.98	0.07	0.77	3.48	3.88	0.29	3.74	
			8	78.41	12.19	0.16	1.08	0.08	0.95	3.63	3.18	0.31	5.95	
			9	78.04	12.42	0.08	0.96	0.06	0.78	3.54	3.80	0.31	4.02	

				10	78.42	12.24	0.10	0.94	0.07	0.78	3.32	3.82	0.31	3.05	
				11	78.01	12.49	0.12	0.93	0.05	0.81	3.37	3.93	0.29	2.75	
				12	78.11	12.39	0.08	1.00	0.08	0.78	3.25	4.01	0.30	3.02	
				13	78.34	12.26	0.09	0.92	0.03	0.80	3.48	3.79	0.30	2.68	
				14	77.89	12.28	0.12	1.04	0.13	0.95	3.46	3.84	0.29	2.85	
				15	78.01	12.35	0.10	0.95	0.05	0.78	3.43	4.02	0.31	3.09	
				16	78.20	12.25	0.14	1.10	0.07	0.96	3.58	3.41	0.28	5.78	
			Mean		78.20	12.32	0.12	1.01	0.07	0.86	3.44	3.69	0.29	3.76	
			StD		0.18	0.09	0.02	0.07	0.02	0.08	0.11	0.26	0.01	1.24	16
CJR-T2	Kaukatea Tephra	BM35 377 408		1	77.06	12.77	0.14	1.73	0.07	1.02	3.74	3.22	0.24	7.03	
				2	76.91	12.90	0.15	1.59	0.07	1.03	3.80	3.30	0.26	5.17	
				3	76.62	12.82	0.15	1.68	0.08	1.05	3.84	3.52	0.24	4.29	
				4	77.22	12.60	0.13	1.44	0.04	0.92	3.86	3.52	0.26	3.84	
				5	77.23	12.63	0.11	1.38	0.07	0.94	4.05	3.35	0.25	3.88	
				6	77.43	12.66	0.10	1.29	0.03	0.95	3.74	3.54	0.26	4.53	
				7	76.99	12.83	0.12	1.53	0.07	1.05	3.82	3.32	0.27	5.11	
				8	76.82	12.85	0.11	1.59	0.07	1.06	3.88	3.36	0.26	5.23	
				9	76.96	12.88	0.12	1.50	0.05	1.02	3.90	3.32	0.24	4.35	
				10	76.65	12.75	0.13	1.63	0.07	1.05	3.94	3.52	0.26	4.04	
				11	77.53	12.60	0.12	1.31	0.05	0.88	3.70	3.59	0.22	4.74	
				12	77.47	12.65	0.11	1.37	0.07	0.92	3.64	3.48	0.29	5.18	
				13	77.25	12.81	0.11	1.34	0.07	1.02	3.84	3.28	0.26	4.71	
				14	77.10	12.80	0.14	1.47	0.07	1.07	3.80	3.30	0.24	6.43	
				15	76.72	12.78	0.16	1.69	0.07	1.05	3.94	3.33	0.25	5.18	
				16	76.77	12.84	0.13	1.57	0.09	1.06	3.97	3.31	0.25	5.23	
				17	77.42	12.49	0.09	1.48	0.03	0.93	3.93	3.35	0.28	5.86	
				18	76.96	12.71	0.14	1.55	0.07	1.05	3.91	3.36	0.25	5.03	
				19	77.13	12.72	0.13	1.47	0.03	1.05	3.89	3.34	0.23	5.11	
			Mean		77.07	12.74	0.13	1.51	0.06	1.01	3.85	3.39	0.25	5.00	
			StD		0.28	0.11	0.02	0.13	0.02	0.06	0.10	0.11	0.02	0.81	19
ATHO-G	Standard	n/a		1	77.16	12.14	0.28	2.91	0.05	1.71	3.09	2.62	0.04	2.45	
				2	76.58	12.19	0.26	3.04	0.08	1.66	3.69	2.44	0.05	1.48	
				3	76.64	12.15	0.27	3.00	0.08	1.68	3.67	2.46	0.05	1.60	
				4	76.98	11.96	0.26	2.79	0.06	1.75	3.71	2.45	0.04	1.52	
				5	76.88	11.96	0.26	2.95	0.07	1.69	3.59	2.57	0.04	1.54	
				6	77.05	11.93	0.25	2.77	0.08	1.76	3.58	2.54	0.03	1.45	
				7	76.66	12.57	0.33	3.35	0.12	1.76	2.59	2.57	0.05	0.65	
				8	75.63	12.44	0.37	3.17	0.12	1.78	3.69	2.73	0.06	0.01	
				9	75.87	12.25	0.35	3.22	0.10	1.71	3.74	2.71	0.04	0.32	
				10	75.78	12.37	0.49	3.31	0.11	1.63	3.50	2.77	0.05	0.25	
				11	75.76	12.33	0.50	3.12	0.13	1.65	3.76	2.71	0.04	0.23	
				12	75.82	12.45	0.55	3.33	0.08	1.56	3.51	2.66	0.04	0.62	
			Mean		76.40	12.23	0.35	3.08	0.09	1.70	3.51	2.60	0.05	1.01	
			StD		0.56	0.20	0.10	0.20	0.03	0.06	0.33	0.11	0.01	0.73	12
VG568	Standard	n/a		1	78.08	12.07	0.09	0.96	0.00	0.44	3.60	4.64	0.12	0.11	
				2	77.89	12.08	0.07	1.04	0.03	0.43	3.72	4.61	0.13	0.06	
				3	78.30	12.03	0.06	0.96	0.02	0.41	3.59	4.49	0.14	2.50	

				4	78.49	12.01	0.08	0.83	0.00	0.43	3.54	4.48	0.14	0.99	
				5	78.12	12.03	0.09	1.06	0.04	0.43	3.68	4.40	0.13	1.57	
				6	78.38	11.83	0.09	0.97	0.03	0.43	3.68	4.46	0.13	0.45	
				7	77.63	12.20	0.00	1.00	0.04	0.47	3.62	4.93	0.11	1.18	
				8	77.52	12.30	0.00	1.12	0.01	0.44	3.54	4.98	0.09	0.55	
				9	77.47	12.14	0.20	1.05	0.06	0.45	3.54	5.01	0.09	0.55	
				10	77.70	12.18	0.06	1.03	0.03	0.42	3.56	4.92	0.09	1.12	
				11	77.49	12.23	0.12	1.10	0.04	0.43	3.57	4.91	0.11	0.98	
				12	77.72	12.20	0.09	1.18	0.02	0.45	3.47	4.75	0.11	0.29	
			Mean		77.90	12.11	0.08	1.03	0.03	0.44	3.59	4.71	0.12	0.86	
			StD		0.35	0.12	0.05	0.09	0.01	0.02	0.07	0.22	0.02	0.66	12
Selected data from Shane 1994 and Pillans et al. (2005)															
PS-3	Potaka Pumice	BL32 790 817	Mean		77.78	12.15	0.12	1.12	0.13	0.95	3.51	4.04	0.23	5.51	
			StD		0.27	0.1	0.03	0.18	0.02	0.11	0.16	0.12	0.23	1.59	9
BP-478/16	Kaukatea Pumice	BL33 969 725	Mean		76.27	12.77	0.22	1.63	0.16	1.07	4.27	3.4	0.21	6.25	
			StD		0.37	0.16	0.03	0.15	0.03	0.06	0.16	0.25	0.03	1.21	11
BP-484	Potaka Pumice	BL33 965 741	Mean		77.84	12.15	0.1	1.09	0.11	0.93	3.69	3.97	0.22	3.28	
			StD		0.49	0.16	0.03	0.12	0.03	0.1	0.11	0.15	0.03	1.05	18
BP-506A	Kaukatea Pumice	BL34 157 660	Mean		75.99	12.96	0.2	1.55	0.14	1.05	4.39	3.54	0.19	5.56	
			StD		0.27	0.17	0.04	0.11	0.03	0.09	0.16	0.22	0.03	0.85	7
BP-485	Potaka Pumice	BL34 187 675	Mean		77.8	12.12	0.1	1.08	0.09	0.88	3.59	4.12	0.22	3.56	
			StD		0.28	0.15	0.04	0.14	0.03	0.09	0.18	0.24	0.03	1.18	13
BP-305	Potaka Pumice	BL34 257 694	Mean		78.07	11.87	0.14	1.19	0.1	0.99	3.72	3.68	0.22	6.01	
			StD		0.22	0.16	0.02	0.08	0.05	0.06	0.19	0.15	0.03	0.52	11

Supplementary Data File 5B

Macrofossil paleoecology of the Waitapu Shell Conglomerate

The fossil fauna of the Waitapu Shell Conglomerate (Table 1, Fig. 1) provide a glimpse into a range of ecological zones present at the time of deposition. Nevertheless, these interpretations must be treated with caution, given the substantial reworking, selective sorting and concentration of more robust specimens within the interpreted shallow-water high-energy environment (Cooper et al. 2006).

Some specimens, such as the single large shell of the restricted Nukumaruan species *Struthiolaria frazeri*, have been derived from underlying rocks, so a variety of other specimens likely have as well. This is not surprising, given the erosional nature of the deposit. At the Castlecliff Type Section *Barnea similis* is typically found boring the unconformable surfaces between successive cycles (Abbott & Carter 1994; Abbott & Carter 1997; Abbott 1998; Beu 2006), a relationship that also occurs in the Rangitikei area (Abbott 1994). The author has not found deposits containing *B. similis* directly below the Waitapu Shell Conglomerate. However, specimens in growth position occur within siltstone stratigraphically above the Waitapu Shell Conglomerate (Abbott 1994). We suggest rare dislodged specimens became incorporated within the Waitapu Shell Conglomerate from laterally adjacent hard ground areas, where suitable habitat for boring bivalves was present. This hard ground likely comprised a shelf of consolidated Pleistocene siltstone exposed by wave erosion/transgressive ravinement, similar to environments along the southern Taranaki Bight today. Other species certainly have been transported far from their life environments, particularly the soft-bottom shelf-dwelling Gastropoda *Alcithoe fusus, Alcithoe arabica, Aeneator*

marshalli, Austrofusus glans, Amalda novaezelandiae, Amalda mucronata and *Poirieria zelandica.*

Estuarine species *Austrovenus stutchburyi, Cyclomactra tristis, Paphies australis, Cominella glandiformis* and *Cominella adspersa* are rare in the outcrop and typically their shells are extremely abraded, suggesting substantial transportation and reworking. Dominant open coast to sandy nearshore species, particularly *Paphies donacina* and *P. delta,* while disarticulated, appear the least worn and significantly out-number other species within the assemblage, suggesting the depositional environment was supplied by a nearby high-energy shoreface environment or that reworking during transgressive ravinement principally involved erosion of shoreface deposits.

Austrovenus stutchburyi is encountered in many sand and mud flats in the outer parts of modern New Zealand estuaries, although larger shells are typically found in the outer parts of bays with higher salinity and more diverse faunas (Beu & Maxwell 1990; Morley & Hayward 2009). The genus is unknown from fully marine situations. Its presence within the Waitapu Shell Conglomerate together with a variety of other species (Fig. 1) is interpreted to represent transportation and reworking of shells from a range of environments, concentrated within a shallow marine environment by wave and tidal action. It is possible the shells of *A. stutchburyi* have been transported a considerable distance from their living habitat, carried by swift tidal currents to a marine setting (Hayward & Stilwell 1995) or reworked from underlying deposits (Abbott 1994).

C. tristis is a deep-burrowing species typically found living together with *Macomona liliana* in the same intertidal flats as *A. stutchburyi,* although located deeper in the substrate (Beu & Maxwell 1990). *Alcithoe arabica* together with *Cominella adspersa* likely actively preyed on *A. stutchburyi* within the intertidal zone, taking shelter amongst the rocky, hard ground areas inhabited by *Ostrea*

chilensis and *Maoricrypta profunda* to retreat whilst laying eggs (Hayward et al. 2001; Hayward et al. 2002). *Paphies australis* is also estuarine, mainly inhabiting the tidal race channels near the mouths of estuaries, but also living near the heads of large bays (Grant-Taylor & Beu 1974; Beu & Maxwell 1990; Morley et al. 2006).

Nearshore to open coast dwelling species are abundant within the Waitapu Shell Conglomerate, including the typical modern day associations of the tuatua species *Paphies donacina* and *Paphies delta* (Beu & De Rooij-Schuiling 1982). Likely the sandy foreshore was similar to stretches of the modern day Rangitikei coastline where tuatua live buried in the intertidal to subtidal sands. The widely ranging suspension feeding turritellid *Maoricolpus roseus* likely inhabited the sandy coastal area together with *Pelicaria vermis*, lying buried immediately beneath the surface of the sand whilst feeding (Morton 1951; Eagle & Hayward 1993; Donald & Spencer 2015). The carnivorous epifaunal gastropod *Tanea zelandica* roamed the sandy coastal area preying on burrowing bivalves.

A hard-ground environment is indicated by *Ostrea chilensis* (Beu 2010), formed by influxes of siliciclastic gravels into the shallow marine environment forming gravel dunes and perhaps localised gravelly foreshores, through wave action, acting to sort and concentrate coarse material in near shore to inner-most shelf environments whilst winnowing away fine silts and sand. Strong tidal currents allowed for siliciclastic bypass and stratigraphic condensation in areas of the sea floor, resulting in a relative enrichment of bioclastic material and creation of low angle shell banks consisting of broken and abraded shell material, crushed by wave action. In places, hard cohesive siltstone was exposed by storm wave erosion including local scouring and creation of rip up clasts, supplementing the abundance of fluvially derived greywacke clasts within hardground areas. Coastal platforms formed of consolidated Pleistocene sedimentary rock stripped bare of surficial sediment provided suitable habitat for *Barnea similis* to bore into, analogous to coastal settings along the southern Taranaki coastline today.

Evidence of a relatively stable gravelly area composed of a mixture of broken shells, greywacke pebbles and clasts of eroded Pleistocene sedimentary rock is suggested by the presence of *Barbatia novaezelandiae*, which lives basally attached in crevices and under stones together with *Ostrea chilensis and Chamaesipho columna* (Hayward & Morley 2002; Morley et al. 2006). The gastropods *Calliostoma punctulatum* and *Coelotrochus tiaratus* prefer to graze hard ground areas, suggesting that an array of bryozoans, sponges and brown algae lined the stones and ledges of the gravelly area. *Ostrea chilensis* lived here, preyed upon by the deadly oyster borer *Haustrum scobina*, which took shelter within crevices offering protection from predators, whilst *Paratrophon sp.* roamed the environment preying on other gastropods, bivalves and barnacles. Among the scavenging whelks, there are two species that lived in this zone including *C. nassoides elegantula* and *Buccinulum vittatum.* We interpret few bivalves to have lived within this gravelly zone, although it was likely inhabited by mussels, oysters and rock borers.

More widely ranging species such as *Purpurocardia purpurata* and *Penion sulcatum* inhabited a soft-bottom zone at inner shelf depths together with the soft-bottom gastropods *Alcithoe sp*. *Aeneator marshalli*, *Austrofusus glans*, and *Poirieria zelandica* (Hayward et al. 1999; Beu 2011). Carnivorous gastropods roamed the soft ground zone such as *Alcithoe arabica,* able to move with ease on soft substrates, feeding on bivalves and laying their eggs in shelly or stony zones of the sea floor (Ponder 1970). Other common gastropods occupying the soft-ground area include the olive shells *Amalda mucronata* and *A. novaezelandiae.*

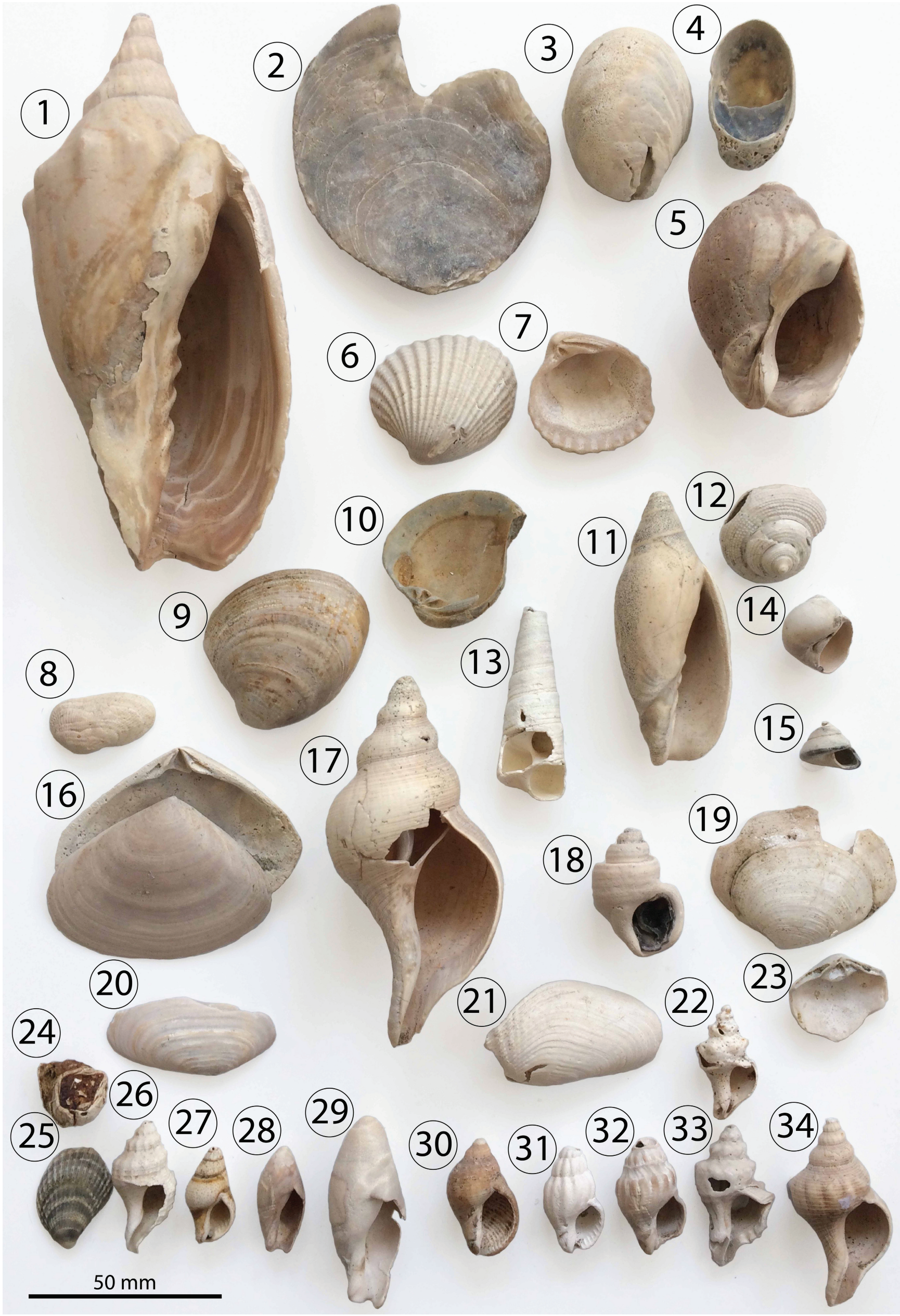

Fig. 1: Fossils from the Waitapu Shell Conglomerate that represent a variety of subtidal to offshore environments: 1) Alcithoe arabica; 2) Ostrea chilensis; 3, 4) Maoricrypta profunda; 5) Cominella adspersa; 6, 7) Purpurocardia purpurata; 8) Barbatia novaezelandiae; 9, 10) Austrovenus stutchburyi; 11) Alcithoe fusus; 12) Calliostoma punctulata; 13) Maoricolpus roseus; 14) Tanea zelandica; 15) Coelotrochus tiaratus; 16) Paphies delta; 17) Aeneator marshalli; 18) Pelicaria vermis; 19, 23) Cyclomactra tristis; 20) Paphies australis; 21) Barnea (Anchomasa) similis; 22, 33) Poireiria zelandica; 24) Chamaesipho columna; 25) Lima zelandica; 26) Austrofusus glans; 27) Buccinulum vittatum; 28) Amalda novaezelandiae; 29) Amalda mucronata; 30) Haustrum scobina; 31) Cominella nassoides elegantula; 32) Cominella glandiformis; 34) Penion sulcatum.

Table 1: List of macrofossils collected from Waitapu Shell Conglomerate type section.

Phylum	Class	Genus and species	Environment
Mollusca	Bivalvia	*Ostrea chilensis* Philippi (Küster, 1844)	Rocky intertidal
		Barnea (Anchomasa) similis (Gray, 1835)	
		Barbatia novaezelandiae (Smith, 1915)	
		Austrovenus stutchburyi (Wood, 1828)	Estuarine/ lagoonal
		Cyclomactra tristis (Reeve, 1854)	
		Paphies australis (Gmelin, 1791)	
		Paphies delta Beu, 2006	Open coast/shoreface
		Paphies donacina (Spengler, 1793)	
		Purpurocardia purpurata (Deshayes, 1854)	
		Lima zelandica (Sowerby, 1877)	Soft-bottom shelf
	Gastropoda	*Calliostoma punctulatum* (Martyn, 1784)	Rocky intertidal
		Coelotrochus tiaratus (Quoy & Gaimard, 1834)	
		Buccinulum vittatum (Quoy & Gaimard, 1833)	
		Haustrum scobina (Quoy & Gaimard, 1833)	
		Paratrophon sp.	
		Cominella adspersa (Bruguière, 1789)	Estuarine/ lagoonal
		Cominella glandiformis (Reeve, 1846)	
		Maoricolpus roseus (Quoy & Gaimard, 1834)	Open coast/shoreface
		Maoricrypta profunda (Hutton, 1873)	
		Tanea zelandica (Quoy & Gaimard, 1832)	
		Pelicaria vermis (Martyn, 1784)	
		Cominella nassoides elegantula (Finlay, 1926)	Soft-bottom shallow water to shelf
		Alcithoe arabica (Gmelin, 1791)	
		Penion sulcatum (Lamarck, 1816)	
		Alcithoe fusus (Quoy & Gaimard, 1833)	Soft-bottom shelf
		Aeneator marshalli (Murdoch, 1924)	
		Austrofusus glans (Röding, 1798))	
		Amalda novaezelandiae (Sowerby, 1859)	
		Amalda mucronata (Sowerby, 1830)	
		Poirieria zelandica (Quoy & Gaimard, 1833)	
Arthropoda		*Chamaesipho columna* (Spengler, 1790)	Rocky intertidal

Supplementary Data File 5C

Stratigraphic unit/section	Clast №	L	I	S	S/I	I/L	S/L	L-I	L-S	(L-I)/(L-S)
Whareroa Conglomerate/Pohangina section		1	65	50	40	0.80	0.77	0.62	15.00	25.00	0.60
		2	35	34	32	0.94	0.97	0.91	1.00	3.00	0.33
L=Long Axis		3	68	50	39	0.78	0.74	0.57	18.00	29.00	0.62
I= Intermediate Axis		4	48	34	25	0.74	0.71	0.52	14.00	23.00	0.61
S=Short Axis		5	35	24	20	0.83	0.69	0.57	11.00	15.00	0.73
		6	17	15	14	0.93	0.88	0.82	2.00	3.00	0.67
		7	33	30	26	0.87	0.91	0.79	3.00	7.00	0.43
		8	32	27	17	0.63	0.84	0.53	5.00	15.00	0.33
		9	18	16	15	0.94	0.89	0.83	2.00	3.00	0.67
		10	19	17	16	0.94	0.89	0.84	2.00	3.00	0.67
		11	56	51	40	0.78	0.91	0.71	5.00	16.00	0.31
		12	34	31	25	0.81	0.91	0.74	3.00	9.00	0.33
		13	24	20	17	0.85	0.83	0.71	4.00	7.00	0.57
		14	39	35	30	0.86	0.90	0.77	4.00	9.00	0.44
		15	37	32	28	0.88	0.86	0.76	5.00	9.00	0.56
		16	22	16	14	0.88	0.73	0.64	6.00	8.00	0.75
		17	8	7	6	0.86	0.88	0.75	1.00	2.00	0.50
		18	25	19	14	0.74	0.76	0.56	6.00	11.00	0.55
		19	16	15	11	0.73	0.94	0.69	1.00	5.00	0.20
		20	47	34	20	0.59	0.72	0.43	13.00	27.00	0.48
		21	23	20	16	0.80	0.87	0.70	3.00	7.00	0.43
		22	37	31	26	0.84	0.84	0.70	6.00	11.00	0.55
		23	7	6	5	0.83	0.86	0.71	1.00	2.00	0.50
		24	32	20	10	0.50	0.63	0.31	12.00	22.00	0.55
		25	38	27	24	0.89	0.71	0.63	11.00	14.00	0.79
		26	39	32	26	0.81	0.82	0.67	7.00	13.00	0.54
		27	59	50	44	0.88	0.85	0.75	9.00	15.00	0.60
		28	24	21	19	0.90	0.88	0.79	3.00	5.00	0.60
		29	34	30	25	0.83	0.88	0.74	4.00	9.00	0.44
		30	28	16	11	0.69	0.57	0.39	12.00	17.00	0.71
		31	49	43	38	0.88	0.88	0.78	6.00	11.00	0.55
		32	36	32	27	0.84	0.89	0.75	4.00	9.00	0.44
		33	15	10	6	0.60	0.67	0.40	5.00	9.00	0.56
		34	23	22	20	0.91	0.96	0.87	1.00	3.00	0.33
		35	5	4	3	0.75	0.80	0.60	1.00	2.00	0.50
		36	31	23	19	0.83	0.74	0.61	8.00	12.00	0.67
		37	51	38	29	0.76	0.75	0.57	13.00	22.00	0.59
		38	57	40	25	0.63	0.70	0.44	17.00	32.00	0.53
		39	22	18	14	0.78	0.82	0.64	4.00	8.00	0.50
		40	53	41	30	0.73	0.77	0.57	12.00	23.00	0.52
		41	14	12	9	0.75	0.86	0.64	2.00	5.00	0.40
		42	15	11	10	0.91	0.73	0.67	4.00	5.00	0.80
		43	3	2	1	0.50	0.67	0.33	1.00	2.00	0.50
		44	15	14	12	0.86	0.93	0.80	1.00	3.00	0.33
		45	30	26	21	0.81	0.87	0.70	4.00	9.00	0.44
		46	23	20	17	0.85	0.87	0.74	3.00	6.00	0.50
		47	52	41	31	0.76	0.79	0.60	11.00	21.00	0.52

	48	25	18	13	0.72	0.72	0.52	7.00	12.00	0.58
	49	58	43	25	0.58	0.74	0.43	15.00	33.00	0.45
	50	20	17	15	0.88	0.85	0.75	3.00	5.00	0.60
Whareroa conglomerate/ Beaconsfield Valley section	1	36	28	22	0.79	0.78	0.61	8.00	14.00	0.57
	2	50	29	22	0.76	0.58	0.44	21.00	28.00	0.75
	3	35	34	19	0.56	0.97	0.54	1.00	16.00	0.06
	4	24	16	8	0.50	0.67	0.33	8.00	16.00	0.50
	5	45	36	22	0.61	0.80	0.49	9.00	23.00	0.39
	6	28	23	17	0.74	0.82	0.61	5.00	11.00	0.45
	7	28	23	13	0.57	0.82	0.46	5.00	15.00	0.33
	8	31	28	17	0.61	0.90	0.55	3.00	14.00	0.21
	9	22	19	15	0.79	0.86	0.68	3.00	7.00	0.43
	10	33	30	15	0.50	0.91	0.45	3.00	18.00	0.17
	11	36	23	16	0.70	0.64	0.44	13.00	20.00	0.65
	12	17	16	14	0.88	0.94	0.82	1.00	3.00	0.33
	13	24	21	18	0.86	0.88	0.75	3.00	6.00	0.50
	14	23	20	10	0.50	0.87	0.43	3.00	13.00	0.23
	15	16	13	8	0.62	0.81	0.50	3.00	8.00	0.38
	16	42	35	25	0.71	0.83	0.60	7.00	17.00	0.41
	17	17	14	13	0.93	0.82	0.76	3.00	4.00	0.75
	18	26	19	12	0.63	0.73	0.46	7.00	14.00	0.50
	19	16	13	4	0.31	0.81	0.25	3.00	12.00	0.25
	20	16	13	10	0.77	0.81	0.63	3.00	6.00	0.50
	21	17	13	8	0.62	0.76	0.47	4.00	9.00	0.44
	22	20	15	8	0.53	0.75	0.40	5.00	12.00	0.42
	23	26	18	9	0.50	0.69	0.35	8.00	17.00	0.47
	24	14	13	12	0.92	0.93	0.86	1.00	2.00	0.50
	25	13	12	10	0.83	0.92	0.77	1.00	3.00	0.33
	26	18	12	8	0.67	0.67	0.44	6.00	10.00	0.60
	27	14	13	7	0.54	0.93	0.50	1.00	7.00	0.14
	28	17	12	7	0.58	0.71	0.41	5.00	10.00	0.50
	29	18	17	9	0.53	0.94	0.50	1.00	9.00	0.11
	30	21	17	11	0.65	0.81	0.52	4.00	10.00	0.40
	31	22	21	10	0.48	0.95	0.45	1.00	12.00	0.08
	32	46	31	10	0.32	0.67	0.22	15.00	36.00	0.42
	33	18	12	6	0.50	0.67	0.33	6.00	12.00	0.50
	34	49	34	20	0.59	0.69	0.41	15.00	29.00	0.52
	35	20	14	10	0.71	0.70	0.50	6.00	10.00	0.60
	36	33	27	19	0.70	0.82	0.58	6.00	14.00	0.43
	37	36	22	15	0.68	0.61	0.42	14.00	21.00	0.67
	38	17	16	11	0.69	0.94	0.65	1.00	6.00	0.17
	39	20	16	14	0.88	0.80	0.70	4.00	6.00	0.67
	40	17	15	7	0.47	0.88	0.41	2.00	10.00	0.20
	41	16	15	14	0.93	0.94	0.88	1.00	2.00	0.50
	42	15	12	9	0.75	0.80	0.60	3.00	6.00	0.50
	43	21	16	15	0.94	0.76	0.71	5.00	6.00	0.83
	44	14	13	15	1.15	0.93	1.07	1.00	-1.00	-1.00
	45	14	11	5	0.45	0.79	0.36	3.00	9.00	0.33

	46	18	13	6	0.46	0.72	0.33	5.00	12.00	0.42
	47	21	15	13	0.87	0.71	0.62	6.00	8.00	0.75
	48	16	11	7	0.64	0.69	0.44	5.00	9.00	0.56
	49	17	14	12	0.86	0.82	0.71	3.00	5.00	0.60
	50	15	12	6	0.50	0.80	0.40	3.00	9.00	0.33
Waitapu Shell Conglomerate/Waitapu Stream section	1	36	31	12	0.39	0.86	0.33	5.00	24.00	0.21
	2	44	28	11	0.39	0.64	0.25	16.00	33.00	0.48
	3	65	35	17	0.49	0.54	0.26	30.00	48.00	0.63
	4	50	28	15	0.54	0.56	0.30	22.00	35.00	0.63
	5	37	21	14	0.67	0.57	0.38	16.00	23.00	0.70
	6	48	45	30	0.67	0.94	0.63	3.00	18.00	0.17
	7	35	23	15	0.65	0.66	0.43	12.00	20.00	0.60
	8	50	26	14	0.54	0.52	0.28	24.00	36.00	0.67
	9	36	19	13	0.68	0.53	0.36	17.00	23.00	0.74
	10	50	31	18	0.58	0.62	0.36	19.00	32.00	0.59
	11	72	33	11	0.33	0.46	0.15	39.00	61.00	0.64
	12	25	23	9	0.39	0.92	0.36	2.00	16.00	0.13
	13	26	18	7	0.39	0.69	0.27	8.00	19.00	0.42
	14	32	14	8	0.57	0.44	0.25	18.00	24.00	0.75
	15	46	27	12	0.44	0.59	0.26	19.00	34.00	0.56
	16	41	28	3	0.11	0.68	0.07	13.00	38.00	0.34
	17	40	19	9	0.47	0.48	0.23	21.00	31.00	0.68
	18	31	16	8	0.50	0.52	0.26	15.00	23.00	0.65
	19	106	90	39	0.43	0.85	0.37	16.00	67.00	0.24
	20	54	33	14	0.42	0.61	0.26	21.00	40.00	0.53
	21	48	14	7	0.50	0.29	0.15	34.00	41.00	0.83
	22	87	61	23	0.38	0.70	0.26	26.00	64.00	0.41
	23	21	17	1	0.06	0.81	0.05	4.00	20.00	0.20
	24	42	29	17	0.59	0.69	0.40	13.00	25.00	0.52
	25	58	33	16	0.48	0.57	0.28	25.00	42.00	0.60
	26	44	18	13	0.72	0.41	0.30	26.00	31.00	0.84
	27	54	15	8	0.53	0.28	0.15	39.00	46.00	0.85
	28	28	19	5	0.26	0.68	0.18	9.00	23.00	0.39
	29	35	13	9	0.69	0.37	0.26	22.00	26.00	0.85
	30	44	17	11	0.65	0.39	0.25	27.00	33.00	0.82
	31	25	11	8	0.73	0.44	0.32	14.00	17.00	0.82
	32	33	19	15	0.79	0.58	0.45	14.00	18.00	0.78
	33	36	15	11	0.73	0.42	0.31	21.00	25.00	0.84
	34	50	31	12	0.39	0.62	0.24	19.00	38.00	0.50
	35	2	21	5	0.24	10.50	2.50	-19.00	-3.00	6.33
	36	24	15	9	0.60	0.63	0.38	9.00	15.00	0.60
	37	19	17	9	0.53	0.89	0.47	2.00	10.00	0.20
	38	27	12	4	0.33	0.44	0.15	15.00	23.00	0.65
	39	20	14	6	0.43	0.70	0.30	6.00	14.00	0.43
	40	46	41	21	0.51	0.89	0.46	5.00	25.00	0.20
	41	32	14	11	0.79	0.44	0.34	18.00	21.00	0.86
	42	36	16	10	0.63	0.44	0.28	20.00	26.00	0.77
	43	33	13	10	0.77	0.39	0.30	20.00	23.00	0.87

	44	31	20	9	0.45	0.65	0.29	11.00	22.00	0.50
	45	19	9	5	0.56	0.47	0.26	10.00	14.00	0.71
	46	18	17	4	0.24	0.94	0.22	1.00	14.00	0.07
	47	26	17	10	0.59	0.65	0.38	9.00	16.00	0.56
	48	30	18	8	0.44	0.60	0.27	12.00	22.00	0.55
	49	41	25	10	0.40	0.61	0.24	16.00	31.00	0.52
	50	20	15	3	0.20	0.75	0.15	5.00	17.00	0.29
Makuhou Shell Conglomerate/Turakina section	1	53	35	6	0.17	0.66	0.11	18.00	47.00	0.38
	2	43	24	19	0.79	0.56	0.44	19.00	24.00	0.79
	3	40	15	12	0.80	0.38	0.30	25.00	28.00	0.89
	4	36	22	18	0.82	0.61	0.50	14.00	18.00	0.78
	5	36	22	17	0.77	0.61	0.47	14.00	19.00	0.74
	6	30	22	17	0.77	0.73	0.57	8.00	13.00	0.62
	7	26	15	12	0.80	0.58	0.46	11.00	14.00	0.79
	8	28	22	6	0.27	0.79	0.21	6.00	22.00	0.27
	9	29	16	10	0.63	0.55	0.34	13.00	19.00	0.68
	10	60	33	5	0.15	0.55	0.08	27.00	55.00	0.49
	11	36	24	16	0.67	0.67	0.44	12.00	20.00	0.60
	12	31	22	16	0.73	0.71	0.52	9.00	15.00	0.60
	13	38	28	19	0.68	0.74	0.50	10.00	19.00	0.53
	14	32	23	17	0.74	0.72	0.53	9.00	15.00	0.60
	15	23	15	4	0.27	0.65	0.17	8.00	19.00	0.42
	16	33	22	10	0.45	0.67	0.30	11.00	23.00	0.48
	17	29	20	13	0.65	0.69	0.45	9.00	16.00	0.56
	18	27	23	10	0.43	0.85	0.37	4.00	17.00	0.24
	19	32	22	20	0.91	0.69	0.63	10.00	12.00	0.83
	20	27	14	8	0.57	0.52	0.30	13.00	19.00	0.68
	21	36	29	14	0.48	0.81	0.39	7.00	22.00	0.32
	22	35	19	16	0.84	0.54	0.46	16.00	19.00	0.84
	23	28	23	13	0.57	0.82	0.46	5.00	15.00	0.33
	24	32	13	12	0.92	0.41	0.38	19.00	20.00	0.95
	25	40	18	14	0.78	0.45	0.35	22.00	26.00	0.85
	26	37	20	12	0.60	0.54	0.32	17.00	25.00	0.68
	27	24	16	8	0.50	0.67	0.33	8.00	16.00	0.50
	28	22	17	7	0.41	0.77	0.32	5.00	15.00	0.33
	29	28	22	14	0.64	0.79	0.50	6.00	14.00	0.43
	30	24	14	9	0.64	0.58	0.38	10.00	15.00	0.67
	31	30	19	9	0.47	0.63	0.30	11.00	21.00	0.52
	32	35	30	19	0.63	0.86	0.54	5.00	16.00	0.31
	33	22	14	9	0.64	0.64	0.41	8.00	13.00	0.62
	34	24	14	8	0.57	0.58	0.33	10.00	16.00	0.63
	35	28	16	9	0.56	0.57	0.32	12.00	19.00	0.63
	36	24	15	9	0.60	0.63	0.38	9.00	15.00	0.60
	37	33	24	18	0.75	0.73	0.55	9.00	15.00	0.60
	38	36	25	8	0.32	0.69	0.22	11.00	28.00	0.39
	39	33	28	15	0.54	0.85	0.45	5.00	18.00	0.28
	40	39	24	12	0.50	0.62	0.31	15.00	27.00	0.56
	41	28	20	16	0.80	0.71	0.57	8.00	12.00	0.67

	42	26	19	11	0.58	0.73	0.42	7.00	15.00	0.47
	43	33	24	13	0.54	0.73	0.39	9.00	20.00	0.45
	44	29	18	14	0.78	0.62	0.48	11.00	15.00	0.73
	45	30	17	14	0.82	0.57	0.47	13.00	16.00	0.81
	46	25	14	11	0.79	0.56	0.44	11.00	14.00	0.79
	47	27	16	13	0.81	0.59	0.48	11.00	14.00	0.79
	48	32	13	9	0.69	0.41	0.28	19.00	23.00	0.83
	49	37	26	14	0.54	0.70	0.38	11.00	23.00	0.48
	50	30	19	12	0.63	0.63	0.40	11.00	18.00	0.61
Makuhou Shell Conglomerate/ Kaimatira Bluff section										
	1	65	54	21	0.39	0.83	0.32	11.00	44.00	0.25
	2	76	47	24	0.51	0.62	0.32	29.00	52.00	0.56
	3	61	47	22	0.47	0.77	0.36	14.00	39.00	0.36
	4	52	45	16	0.36	0.87	0.31	7.00	36.00	0.19
	5	49	31	15	0.48	0.63	0.31	18.00	34.00	0.53
	6	40	30	8	0.27	0.75	0.20	10.00	32.00	0.31
	7	43	14	9	0.64	0.33	0.21	29.00	34.00	0.85
	8	33	23	18	0.78	0.70	0.55	10.00	15.00	0.67
	9	43	37	17	0.46	0.86	0.40	6.00	26.00	0.23
	10	120	101	34	0.34	0.84	0.28	19.00	86.00	0.22
	11	57	49	20	0.41	0.86	0.35	8.00	37.00	0.22
	12	45	41	21	0.51	0.91	0.47	4.00	24.00	0.17
	13	30	25	14	0.56	0.83	0.47	5.00	16.00	0.31
	14	35	16	14	0.88	0.46	0.40	19.00	21.00	0.90
	15	28	24	16	0.67	0.86	0.57	4.00	12.00	0.33
	16	48	34	16	0.47	0.71	0.33	14.00	32.00	0.44
	17	36	24	7	0.29	0.67	0.19	12.00	29.00	0.41
	18	54	46	18	0.39	0.85	0.33	8.00	36.00	0.22
	19	48	38	23	0.61	0.79	0.48	10.00	25.00	0.40
	20	40	23	21	0.91	0.58	0.53	17.00	19.00	0.89
	21	35	25	11	0.44	0.71	0.31	10.00	24.00	0.42
	22	51	47	19	0.40	0.92	0.37	4.00	32.00	0.13
	23	63	48	23	0.48	0.76	0.37	15.00	40.00	0.38
	24	52	39	18	0.46	0.75	0.35	13.00	34.00	0.38
	25	42	20	19	0.95	0.48	0.45	22.00	23.00	0.96
	26	50	33	20	0.61	0.66	0.40	17.00	30.00	0.57
	27	37	20	15	0.75	0.54	0.41	17.00	22.00	0.77
	28	34	26	16	0.62	0.76	0.47	8.00	18.00	0.44
	29	39	25	13	0.52	0.64	0.33	14.00	26.00	0.54
	30	31	25	15	0.60	0.81	0.48	6.00	16.00	0.38
	31	28	23	9	0.39	0.82	0.32	5.00	19.00	0.26
	32	33	25	13	0.52	0.76	0.39	8.00	20.00	0.40
	33	36	24	17	0.71	0.67	0.47	12.00	19.00	0.63
	34	41	30	17	0.57	0.73	0.41	11.00	24.00	0.46
	35	44	22	15	0.68	0.50	0.34	22.00	29.00	0.76
	36	28	22	7	0.32	0.79	0.25	6.00	21.00	0.29
	37	32	20	17	0.85	0.63	0.53	12.00	15.00	0.80
	38	40	17	12	0.71	0.43	0.30	23.00	28.00	0.82

39	31	20	19	0.95	0.65	0.61	11.00	12.00	0.92
40	25	22	14	0.64	0.88	0.56	3.00	11.00	0.27
41	27	21	14	0.67	0.78	0.52	6.00	13.00	0.46
42	27	21	10	0.48	0.78	0.37	6.00	17.00	0.35
43	29	28	10	0.36	0.97	0.34	1.00	19.00	0.05
44	25	24	14	0.58	0.96	0.56	1.00	11.00	0.09
45	22	19	7	0.37	0.86	0.32	3.00	15.00	0.20
46	62	42	17	0.40	0.68	0.27	20.00	45.00	0.44
47	26	23	8	0.35	0.88	0.31	3.00	18.00	0.17
48	25	20	5	0.25	0.80	0.20	5.00	20.00	0.25
49	22	18	10	0.56	0.82	0.45	4.00	12.00	0.33
50	19	15	5	0.33	0.79	0.26	4.00	14.00	0.29

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Supplementary Data File 7A

Sampling locations.

Facies	Formation	Approximate Age	Location (NZTM)
Kaimatira Pumice Sand	Kamatira Pumice Sand Fm.	1 Ma	1831863, 5569983
Mangapipi Conglomerate	Rewa Fm.	1.5-1.2 Ma	1820654, 5570097
Mangarere Sandstone	Mangarere Fm.	2.6-2.4 Ma	1823581, 5586135
Mangarere Siltstone	Mangarere Fm.	2.6-2.4 Ma	1823244, 5586398
Mangaweka Mudstone	Mangaweka Mudstone Fm.	2.8-2.6 Ma	1828419, 5590083

MASSEY UNIVERSITY
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STATEMENT OF CONTRIBUTION
DOCTORATE WITH PUBLICATIONS/MANUSCRIPTS

We, the candidate and the candidate's Primary Supervisor, certify that all co-authors have consented to their work being included in the thesis and they have accepted the candidate's contribution as indicated below in the *Statement of Originality*.

Name of candidate:	Callum Rees
Name/title of Primary Supervisor:	Alan Palmer
Name of Research Output and full reference:	
Rees, C.J., Palmer, A.S., Palmer, J.A., (2019) Geology of the Central Rangitikei District, Whanganui Basin, lower North Island, New Zealand. Paper in prep. 4 sheets+44p.	
In which Chapter is the Manuscript /Published work:	Chapter 3
Please indicate:	
• The percentage of the manuscript/Published Work that was contributed by the candidate:	95
and	
• Describe the contribution that the candidate has made to the Manuscript/Published Work:	
I compiled the research, spent three years mapping the central Rangitikei, wrote the manuscript, and compiled the 1:25 000 geological map series.	
For manuscripts intended for publication please indicate target journal:	
New Zealand Journal of Geology and Geophysics	
Candidate's Signature:	C J Rees
Date:	08/09/2019
Primary Supervisor's Signature:	Alan Palmer
Date:	09/09/2019

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Name/title of Primary Supervisor:	Alan Palmer
Name of Research Output and full reference:	
Rees, C.J., Palmer, A.S., Palmer, J.A., (2019) Tephrostratigraphic constraints on the timing of sedimentation and tectonism in the Whanganui Basin, New Zealand. Currently in review at the New Zealand Journal of Geology and Geophysics. 1-24.	
In which Chapter is the Manuscript /Published work:	Chapter 4
Please indicate:	
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I completed the field work/sampling, sample preparation, compiled the manuscript and designed the figures.	
For manuscripts intended for publication please indicate target journal:	
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Candidate's Signature:	C J Rees
Date:	08/09/2019
Primary Supervisor's Signature:	Alan Palmer
Date:	09/09/2019

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Name of Research Output and full reference:	
Rees, C.J., Palmer, J.A., Palmer, A.S., (2019) Whanganui Basin, an archive of prehistoric earthquakes? Waitapu Shell Conglomerate (c. 0.9 Ma), North Island, New Zealand. New Zealand Journal of Geology and Geophysics 62(2):195-216.	
In which Chapter is the Manuscript /Published work:	Chapter 5
Please indicate:	
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• Describe the contribution that the candidate has made to the Manuscript/Published Work:	
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For manuscripts intended for publication please indicate target journal:	
New Zealand Journal of Geology and Geophysics	
Candidate's Signature:	C J Rees
Date:	08/09/2019
Primary Supervisor's Signature:	Alan Palmer
Date:	09/09/2019

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Name of candidate:	Callum Rees
Name/title of Primary Supervisor:	Alan Palmer
Name of Research Output and full reference:	
Rees, C.J., Palmer, J.A., Palmer, A.S., Singh, R., (2019) Landscape evolution and hydrogeochemical characteristics of the Pourewa Stream catchment, lower North Island, New Zealand. New Zealand Journal of Geology and Geophysics 62(2):147-170.	
In which Chapter is the Manuscript /Published work:	Chapter 6
Please indicate:	
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and	
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For manuscripts intended for publication please indicate target journal:	
New Zealand Journal of Geology and Geophysics	
Candidate's Signature:	C J Rees
Date:	08/09/2019
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Name/title of Primary Supervisor:	Alan Palmer
Name of Research Output and full reference:	
Rees, C.J., Palmer, J.A., Palmer, A.S., Singh, R. (2019) Variation in saturated hydraulic conductivity at the outcrop scale, the Whanganui Basin, New Zealand. Currently in review at Groundwater. 1-34.	
In which Chapter is the Manuscript /Published work:	Chapter 7
Please indicate:	
• The percentage of the manuscript/Published Work that was contributed by the candidate:	95
and	
• Describe the contribution that the candidate has made to the Manuscript/Published Work:	
I completed the field work/sampling, sample preparation, analysis, compiled the manuscript and designed the figures.	
For manuscripts intended for publication please indicate target journal:	
Groundwater	
Candidate's Signature:	C J Rees
Date:	08/09/2019
Primary Supervisor's Signature:	Alan Palmer
Date:	09/09/2019

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Name/title of Primary Supervisor:	Alan Palmer
Name of Research Output and full reference:	
Rees, C. J., Palmer, A. S., Palmer, J.A., (2019) Litho-structural controls on Quaternary landslide distribution in the Rangitikei hill country, North Island, New Zealand, New Zealand Journal of Geology and Geophysics. Published on-line, 1-20	
In which Chapter is the Manuscript /Published work:	Chapter 8
Please indicate:	
• The percentage of the manuscript/Published Work that was contributed by the candidate:	95
and	
• Describe the contribution that the candidate has made to the Manuscript/Published Work:	
I completed the field work, analysis, compiled the manuscript and designed the figures.	
For manuscripts intended for publication please indicate target journal:	
New Zealand Journal of Geology and Geophysics	
Candidate's Signature:	C J Rees
Date:	08/09/2019
Primary Supervisor's Signature:	Alan Palmer
Date:	09/09/2019

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Appendix B

Geological map

The following section presents the new 1:25 000 geological map series of the central Rangitikei. These maps are a compilation of previous work in the Whanganui Basin and field mapping conducted between 2016-2019. Due to the dominance of pastoral farming and the highly erodible nature of the Whanganui-Manawatu hill country, section is often sparse. Exposures are typically concentrated down major river valleys, roads, tracks, scarp slopes and landslide scars. Particularly well cemented or erosion resistant strata within the succession attain prominence in the landscape and can be traced between key sections. These marker horizons, outlined in chapters 3-5, are critical for packaging the succession into groups and formations and provide a vital basis for identifying the relative position of a bed within the succession during fieldwork. An extended geological legend is included here to provide a comprehensive view of the key tie points and marker horizons used during this survey. Accompanying geological cross sections and a 3D geological model are provided to display key structures in the study area and their relationship to landforms.

View east across Beaconsfield Valley, taken upstream of Jens Road. The Ohakea 2 Terrace can be seen in the middle ground.

TOPOGRAPHIC LEGEND

ROADS AND TRACKS

- State highway
- Road surface: metalled / sealed / unmetalled
- Vehicle track
- Foot track
- Tunnel
- Bridge; two lane, one lane
- Ford
- Gate, locked gate, cattlestop

RAILWAYS

- Double or multiple track
- Single track
- Railway station, yard or siding
- Bridge, tunnel
- Level crossing
- Road over railway
- Road over railway

MISCELLANEOUS

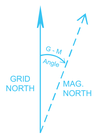
- Large buildings
- Residential area
- Isolated building
- Homestead, stockyard
- Church, cemetery, grave
- Golf course, helipad
- Maori pa, monument, plaque or signpost
- Reservoir covered, reservoir uncovered, tank
- Tower, wind turbine
- Buried gas pipeline
- Power line on pylons
- Power line on poles
- Telephone line (away from roads)
- Aggregate quarry

RELIEF FEATURES

- Index contour (300)
- Intermediate contours
- Beaconed trig station (with trig identification code) (▲BIT0)
- Elevation in metres (▲130 •130)
- Cliff, slip
- Cutting
- Embankment or causeway

WATER FEATURES

- Cold spring
- Watercourse, drain
- Lake or pond
- River



MAGNETIC NORTH on this map is 23° (409 mils) EAST of GRID NORTH during 2014 increasing at a rate of approx 1/2 ° (9 mils) over 20 years

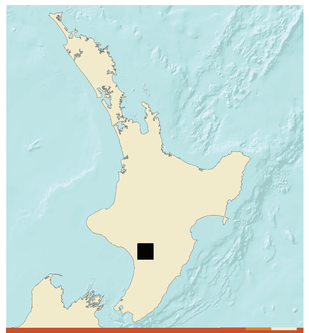
TO GIVE A GRID REFERENCE ON THIS MAP
(To nearest 100 metres)

SAMPLE POINT: *Mangamahu (1802500E 5588800N)*

East		North	
1. Locate the first VERTICAL grid line to the LEFT of the point.		3. Locate the first HORIZONTAL grid line below the point.	
2. Read the grid values labelling the line in either the top or bottom margin.	02	4. Read the grid values labelling the line in either the left or right margin.	88
3. Estimate tenths of a grid square eastwards from the grid line to the point.	5	5. Estimate tenths of a grid square northwards from the grid line to the point.	8
	025		888

Grid Reference: (Quote sheet number first) **Sheet 1 025888**

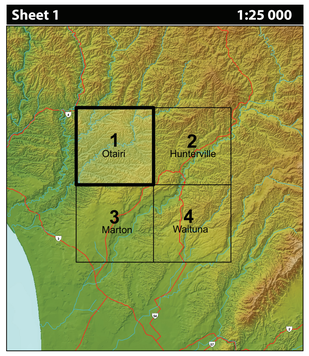
HORIZONTAL DATUM: New Zealand Geodetic Datum 2000 (NZGD2000)
VERTICAL DATUM: Mean Sea Level
PROJECTION: New Zealand Transverse Mercator 2000 (NZTM2000)
THE VERTICAL INTERVAL BETWEEN THE CONTOURS IS 20 METRES HEIGHTS ARE ABOVE MEAN SEA LEVEL



Otairi

GEOLOGY OF CENTRAL RANGITIKEI

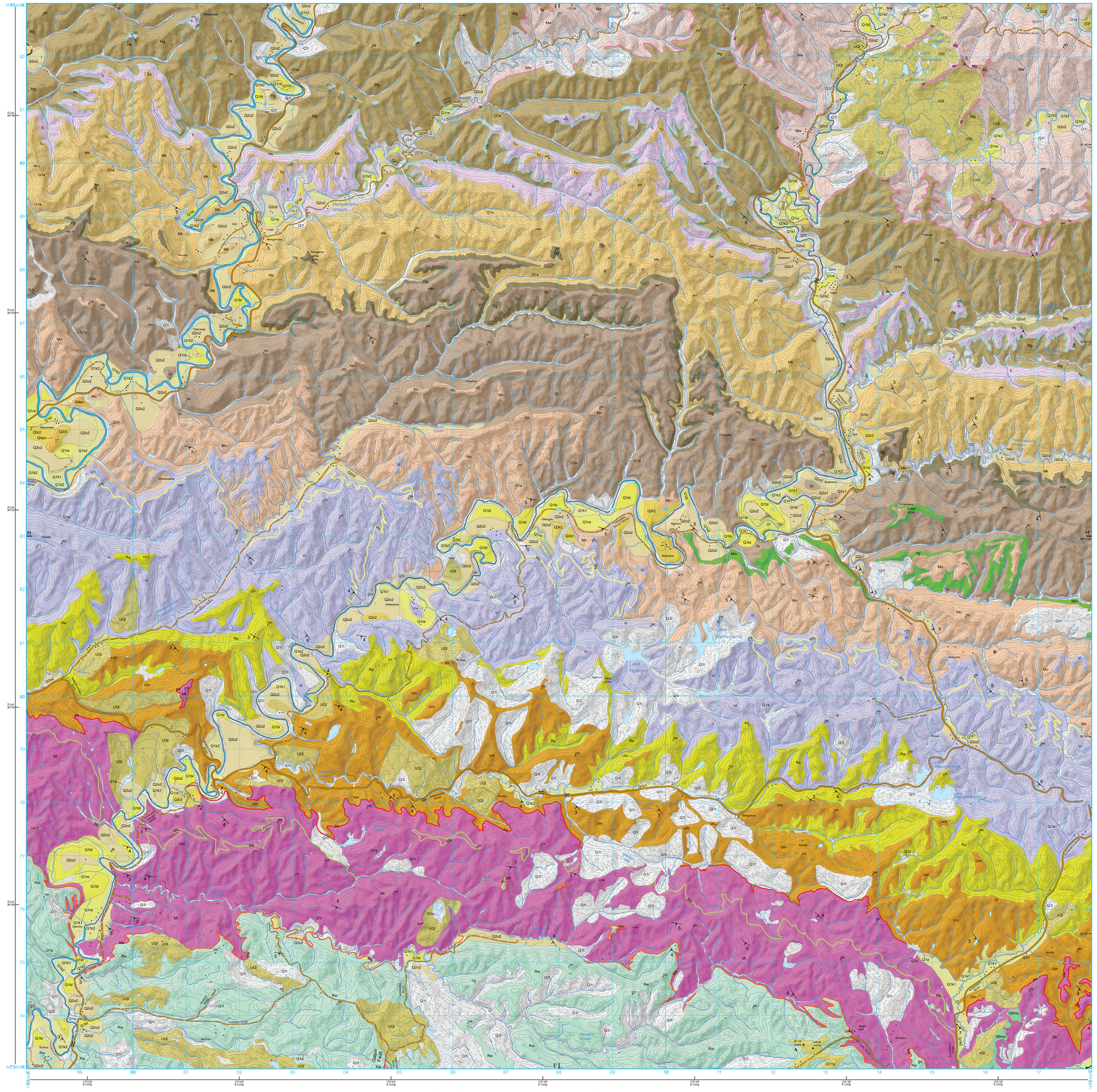
Sheet 1 **1:25 000**



C. Rees

2020

1:25 000 Geological Map of the Central Rangitikei
Sheet 1 - Otairi


55 93 000N
55 73 000N
S Lat 39°48'
S Lat 39°50'
S Lat 39°52'
S Lat 39°54'
S Lat 39°56'
1758 000E
1818 000E
E
E'
H
H'
Mangamahu Stream
Kiorenui Stream
Whakie Creek
Mangara Stream
Te Hue Stream
Lake Namunamu
Lake Ngaruru
Lake Pounamu
Lake Meremere
Lake Waiwiri
Lake Maungaraiaru
Lake Maungaraiaru
Mangamahu
Ruahine
Kaiwhaiwhai
Kaiwhaiwhai
Kaiwhaiwhai

TOPOGRAPHIC LEGEND

ROADS AND TRACKS

State highway
Road surface: metalled / sealed / unmetalled
Vehicle track
Foot track
Tunnel
Bridge; two lane, one lane
Ford
Gate, locked gate, cattlestop

RAILWAYS

Double or multiple track
Single track
Railway station, yard or siding
Bridge, tunnel
Level crossing
Road over railway
Road over railway

MISCELLANEOUS

Large buildings
Residential area
Isolated building
Homestead, stockyard — Ardendee
Church, cemetery, grave
Golf course, helipad
Maori pa, monument, plaque or signpost
Reservoir covered, reservoir uncovered, tank
Tower, wind turbine
Buried gas pipeline
Power line on pylons
Power line on poles
Telephone line (away from roads)
Aggregate quarry

RELIEF FEATURES

Index contour — 300
Intermediate contours
Beaconed trig station (with trig identification code) — ▲BIT0
Elevation in metres — ▲130 130
Cliff, slip
Cutting
Embankment or causeway

WATER FEATURES

Cold spring
Watercourse, drain
Lake or pond
River

GRID NORTH / G - M Angle / MAG. NORTH

MAGNETIC NORTH on this map is 23° (409 mils) EAST of GRID NORTH during 2014 increasing at a rate of approx 1/2 ° (9 mils) over 20 years

TO GIVE A GRID REFERENCE ON THIS MAP
(To nearest 100 metres)

SAMPLE POINT: *Hunterville (1819300E 5575200N)*

East		North	
1. Locate the first VERTICAL grid line to the LEFT of the point.		3. Locate the first HORIZONTAL grid line below the point.	
2. Read the grid values labelling the line in either the top or bottom margin.	19	4. Read the grid values labelling the line in either the left or right margin.	75
3. Estimate tenths of a grid square eastwards from the grid line to the point.	3	5. Estimate tenths of a grid square northwards from the grid line to the point.	2
	193		752

Grid Reference: (Quote sheet number first) **Sheet 2 193752**

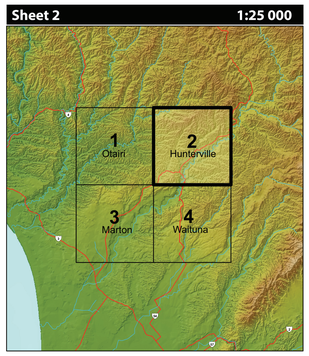
HORIZONTAL DATUM: New Zealand Geodetic Datum 2000 (NZGD2000)
VERTICAL DATUM: Mean Sea Level
PROJECTION: New Zealand Transverse Mercator 2000 (NZTM2000)

THE VERTICAL INTERVAL BETWEEN THE CONTOURS IS 20 METRES HEIGHTS ARE ABOVE MEAN SEA LEVEL

Hunterville

GEOLOGY OF CENTRAL RANGITIKEI

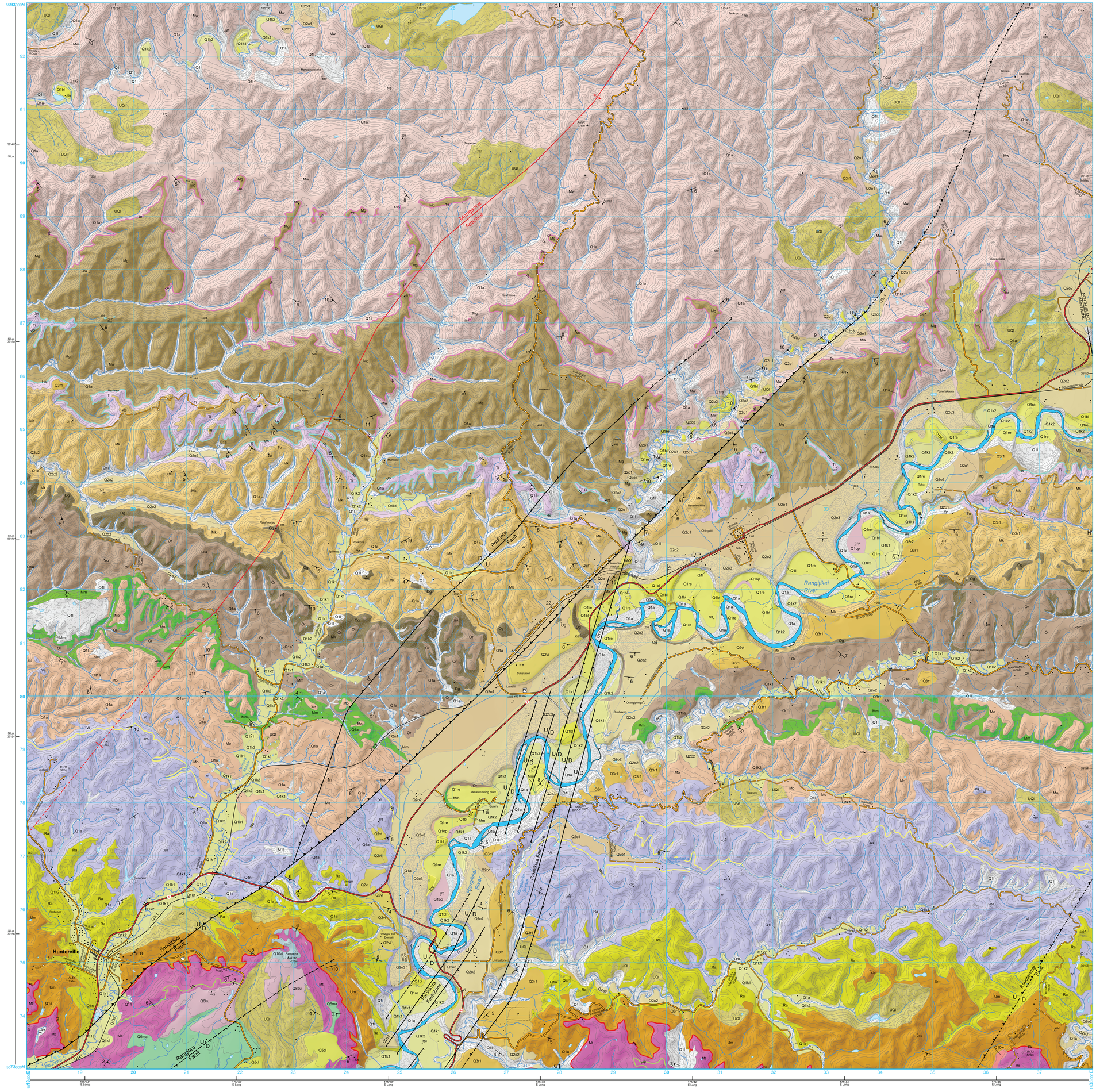
Sheet 2 1:25 000



C. Rees

2020

1:25 000 Geological Map of the Central Rangitikei
Sheet 2 - Hunterville



GEOLOGICAL LEGEND

	River terrace subsets	Landslides	Alluvium	Swamp deposits	Fill	
Lower Kakariki (Q1k2)	Q1k2				Q1n	Fill deposits (Q1n)
Upper Kakariki (Q1k1)	Q1k1			Q1a	Q1a	Swamp deposits (Q1a)
Onepuhi (Q1op)	Q1op		Q1a			Coarse grained fluvial deposits (Q1a)
Rewa (Q1re)	Q1re			Q1a		Fine grained fluvial deposits (Q1a)
Bulls (Q1bl)	Q1bl	Q1l				Recent landslide deposits (Q1l)
Lower Ohakean (Q2o3)	Q2o3					
Middle Ohakean (Q2o2)	Q2o2					
Upper Ohakean (Q2o1)	Q2o1					
Vinegar Hill (Q2vi)	Q2vi	uQl				Undifferentiated landslide deposits (uQl)
Lower Rata (Q3r2)	Q3r2					
Upper Rata (Q3r1)	Q3r1					
Putorino (Q4pu)	Q4pu					
Porewa (Q4po)	Q4po					

		Marine terraces and dunes	
Q5cl	Cliff (Q5cl)	Q1m	Motuiti (Q1m) Q1 dunes
Q5gr	Greatford (Q5gr)	Q1f	Foxton (Q1f) Q1 dunes
Q6ma	Marton (Q6ma)	Q5s	Mt Stewart dune sand (Q5s)
Q8bu	Bumand (Q8bu)	Q7n	Ngarino (Q7n) Cover beds (gravel sand, peat and clay)
Q10al	Aldworth (Q10al)	Q9b	Brunswick (Q9b) Cover beds (gravel sand, peat and clay)
Q10w	Waituna (Q10al)	Q11ar	Ararata (Q11ar) Cover beds (gravel sand, peat and clay)

We	WESTOE FORMATION (We)	POUAKAI GROUP
Ha	HALCOMBE CONGLOMERATE FORMATION (Ha)	
Tp	MANGATAPU FORMATION (Tp)	SHAKESPEARE GROUP
Rc	*RUAMAHANGA CONGLOMERATE MEMBER (Rc)*	
To	TOKORANGI FORMATION (To)	
Tc	*TOMS CONGLOMERATE MEMBER (Tc)*	
Reu	REU REU FORMATION (Reu)	KAI IWI GROUP
Wos	*WAIOMIO SHELL BED MEMBER (Wos)*	
Wai	WAIOMIO FORMATION (Wai)	
Wap	*WAITAPU SHELL CONGLOMERATE MEMBER (Wtp)*	
Kai	KAIMATIRA PUMICE SAND FORMATION (Kai)	
Pp	*POTAKA PUMICE MEMBER (Pp)*	
Rw	REWA FORMATION (Rw)	OKEHU GROUP
Ma	*MANGAPIPI CONGLOMERATE MEMBER (Ma)*	
Mt	MAKIRIKIRI TUFF FORMATION (Mt)	
Mp	*MANGAPIPI MEMBER (Mp)*	
Pk	*PAKIHIKURA PUMICE MEMBER (Pk)*	
Um	UPPER MAXWELL FORMATION (Um)	MAXWELL GROUP
Ra	RATAITI FORMATION (Ra)	
Vi	VINEGAR HILL FORMATION (Vi)	RANGITIKEI GROUP
Ws	*WAIPURU SHELL BED MEMBER (Ws)*	
Mo	MANGAONOHO FORMATION (Mo)	
Mm	*MANGAMAKO SHELL BED MEMBER (Mm).*	
Or	ORANGIPONGO FORMATION (Or)	
Og	*OHINGAITI SAND MEMBER (Og)*	
Mk	MAKOHINE FORMATION (Mk)	
Tu	*TUHA SAND MEMBER (Tu)*	
Ti	TIKAPU FORMATION (Ti)	
Hs	*HAUTAWA SHELL BED MEMBER (Hs)*	
Mg	MANGARERE FORMATION (Mg)	
Te	*TE RIMU SAND MEMBER (Te)*	
Mw	MANGAWEKA MUDSTONE FORMATION (Mw)	PAPARANGI GROUP

Active faults and folds	*Inactive faults and folds*
Accurate normal	Accurate normal
Approximate normal	Approximate normal
Accurate reverse	Accurate reverse
Approximate reverse	Approximate reverse
Accurate Anticline	Approximate anticline
Approximate Anticline	Approximate syncline
Approximate Syncline	Dip and strike

Topographic data sourced from the LINZ 1:50 000 Data Set
Licensed under the Creative Commons Attribution 4.0 International Licence
Representation of a road or track does not necessarily indicate public right of access

TOPOGRAPHIC LEGEND

ROADS AND TRACKS

- State highway
- Road surface: metalled; sealed; unmetalled
- Vehicle track
- Foot track
- Tunnel
- Bridge; two lane, one lane
- Ford
- Gate, locked gate, cattlestop

RAILWAYS

- Double or multiple track
- Single track
- Railway station, yard or siding
- Bridge, tunnel
- Level crossing
- Road over railway
- Road over railway

MISCELLANEOUS

- Large buildings
- Residential area
- Isolated building
- Homestead, stockyard (Ardendee)
- Church, cemetery, grave
- Golf course, helipad
- Maori pa, monument, plaque or signpost
- Reservoir covered, reservoir uncovered, tank
- Tower, wind turbine
- Buried gas pipeline
- Power line on pylons
- Power line on poles
- Telephone line (away from roads)
- Aggregate quarry

RELIEF FEATURES

- Index contour (300)
- Intermediate contours
- Beaconed trig station (with trig identification code) (▲BIT0)
- Elevation in metres (▲130, ·130)
- Cliff, slip
- Cutting
- Embankment or causeway

WATER FEATURES

- Cold spring
- Watercourse, drain
- Lake or pond
- River

GRID NORTH / G–M Angle / MAG. NORTH

MAGNETIC NORTH on this map is 23° (409 mils) EAST of GRID NORTH during 2014 increasing at a rate of approx 1/2 ° (9 mils) over 20 years

TO GIVE A GRID REFERENCE ON THIS MAP
(To nearest 100 metres)

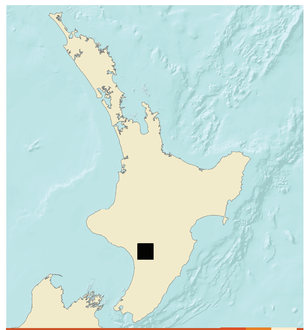
SAMPLE POINT: *Marton (1802400E 5560900N)*

East		North	
1. Locate the first VERTICAL grid line to the LEFT of the point.	02	3. Locate the first HORIZONTAL grid line below the point.	60
2. Read the grid values labelling the line in either the top or bottom margin.		4. Read the grid values labelling the line in either the left or right margin.	
3. Estimate tenths of a grid square eastwards from the grid line to the point.	4	5. Estimate tenths of a grid square northwards from the grid line to the point.	9
	024		609

Grid Reference: (Quote sheet number first) **Sheet 3 024609**

HORIZONTAL DATUM: New Zealand Geodetic Datum 2000 (NZGD2000)
VERTICAL DATUM: Mean Sea Level
PROJECTION: New Zealand Transverse Mercator 2000 (NZTM2000)

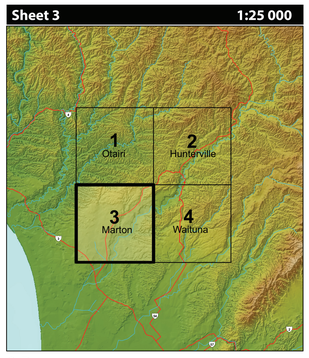
THE VERTICAL INTERVAL BETWEEN THE CONTOURS IS 20 METRES HEIGHTS ARE ABOVE MEAN SEA LEVEL



Marton

GEOLOGY OF CENTRAL RANGITIKEI

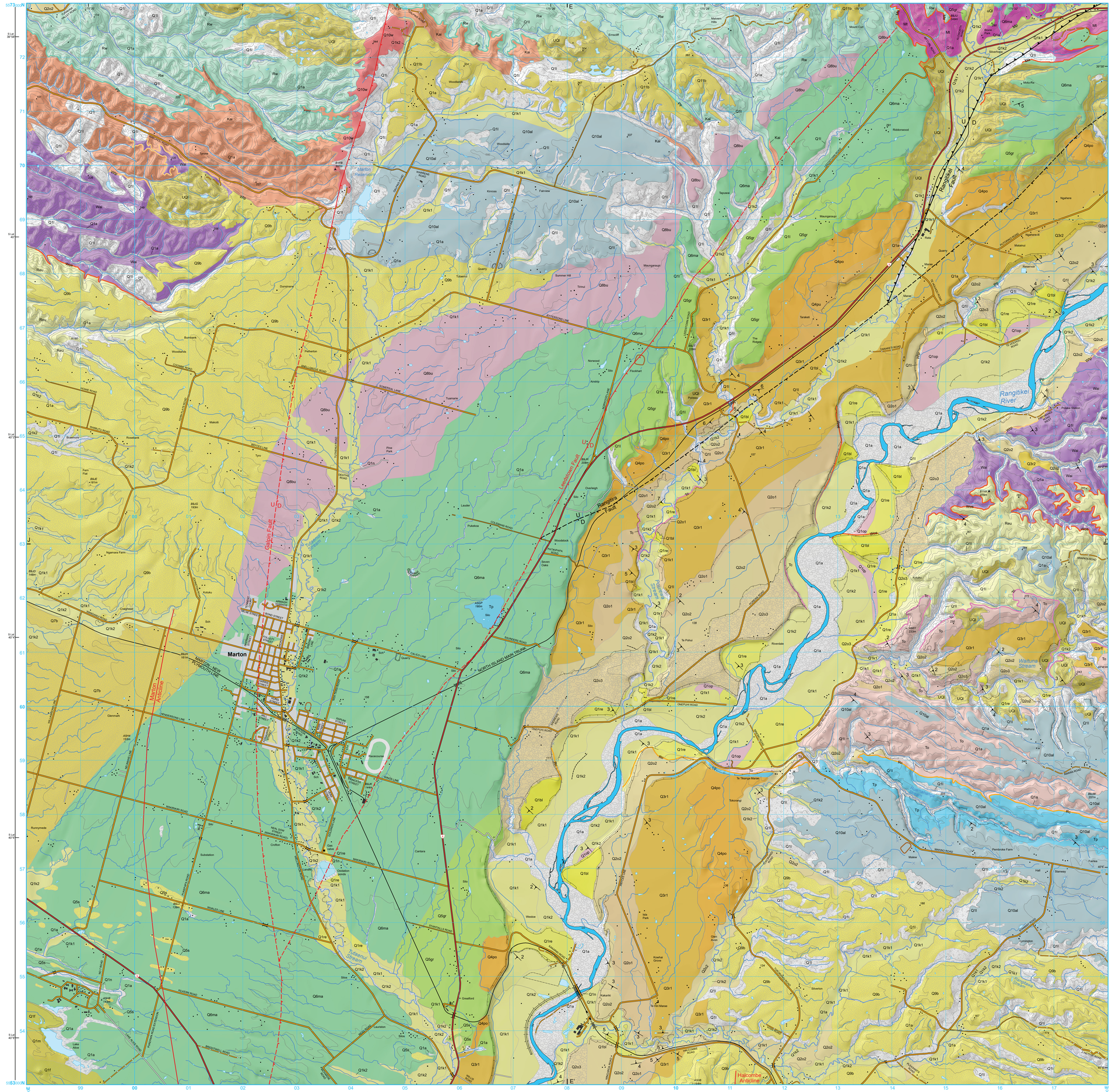
Sheet 3 **1:25 000**



C. Rees

2020

1:25 000 Geological Map of the Central Rangitikei
Sheet 3 - Marton


Marton
Marton Anticline
Galpin Fault
Rangitikei Fault
Leedstown Fault
Halcombe Anticline
Rangitikei River
Tutaenui Stream
Waituna Stream
Marton Reservoir
Marton Racecourse
Marton Cemetery
Marton Golf Course
Marton Quarry
Marton Landfill
Marton Substation
Marton Gas Valve
Oxidation Ponds
Marton Water Supply Bore
Marton Water Supply Intake
Marton Water Supply Reservoir
Marton Water Supply Treatment Plant
Marton Water Supply Tank

TOPOGRAPHIC LEGEND

ROADS AND TRACKS

- State highway
- Road surface: metalled / sealed / unmetalled
- Vehicle track
- Foot track
- Tunnel
- Bridge; two lane, one lane
- Ford
- Gate, locked gate, cattlestop

RAILWAYS

- Double or multiple track
- Single track
- Railway station, yard or siding
- Bridge, tunnel
- Level crossing
- Road over railway
- Road over railway

MISCELLANEOUS

- Large buildings
- Residential area
- Isolated building
- Homestead, stockyard (Ardendee)
- Church, cemetery, grave
- Golf course, helipad
- Maori pa, monument, plaque or signpost
- Reservoir covered, reservoir uncovered, tank
- Tower, wind turbine
- Buried gas pipeline
- Power line on pylons
- Power line on poles
- Telephone line (away from roads)
- Aggregate quarry

RELIEF FEATURES

- Index contour (300)
- Intermediate contours
- Beaconed trig station (with trig identification code) (▲BIT0)
- Elevation in metres (▲130 ·130)
- Cliff, slip
- Cutting
- Embankment or causeway

WATER FEATURES

- Cold spring
- Watercourse, drain
- Lake or pond
- River

MAGNETIC NORTH on this map is 23° (409 mils) EAST of GRID NORTH during 2014 increasing at a rate of approx 1/2 ° (9 mils) over 20 years

TO GIVE A GRID REFERENCE ON THIS MAP
(To nearest 100 metres)

SAMPLE POINT: *Waituna West (1825500E 5563900N)*

East		North	
1. Locate the first VERTICAL grid line to the LEFT of the point.	25	3. Locate the first HORIZONTAL grid line below the point.	63
2. Read the grid values labelling the line in either the top or bottom margin.		4. Read the grid values labelling the line in either the left or right margin.	
3. Estimate tenths of a grid square eastwards from the grid line to the point.	5	5. Estimate tenths of a grid square northwards from the grid line to the point.	9
	255		639

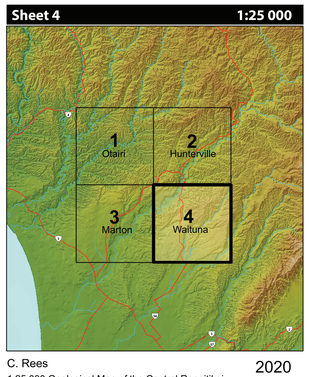
Grid Reference: (Quote sheet number first) **Sheet 4 255639**

HORIZONTAL DATUM: New Zealand Geodetic Datum 2000 (NZGD2000)
VERTICAL DATUM: Mean Sea Level
PROJECTION: New Zealand Transverse Mercator 2000 (NZTM2000)

THE VERTICAL INTERVAL BETWEEN THE CONTOURS IS 20 METRES HEIGHTS ARE ABOVE MEAN SEA LEVEL

Waituna

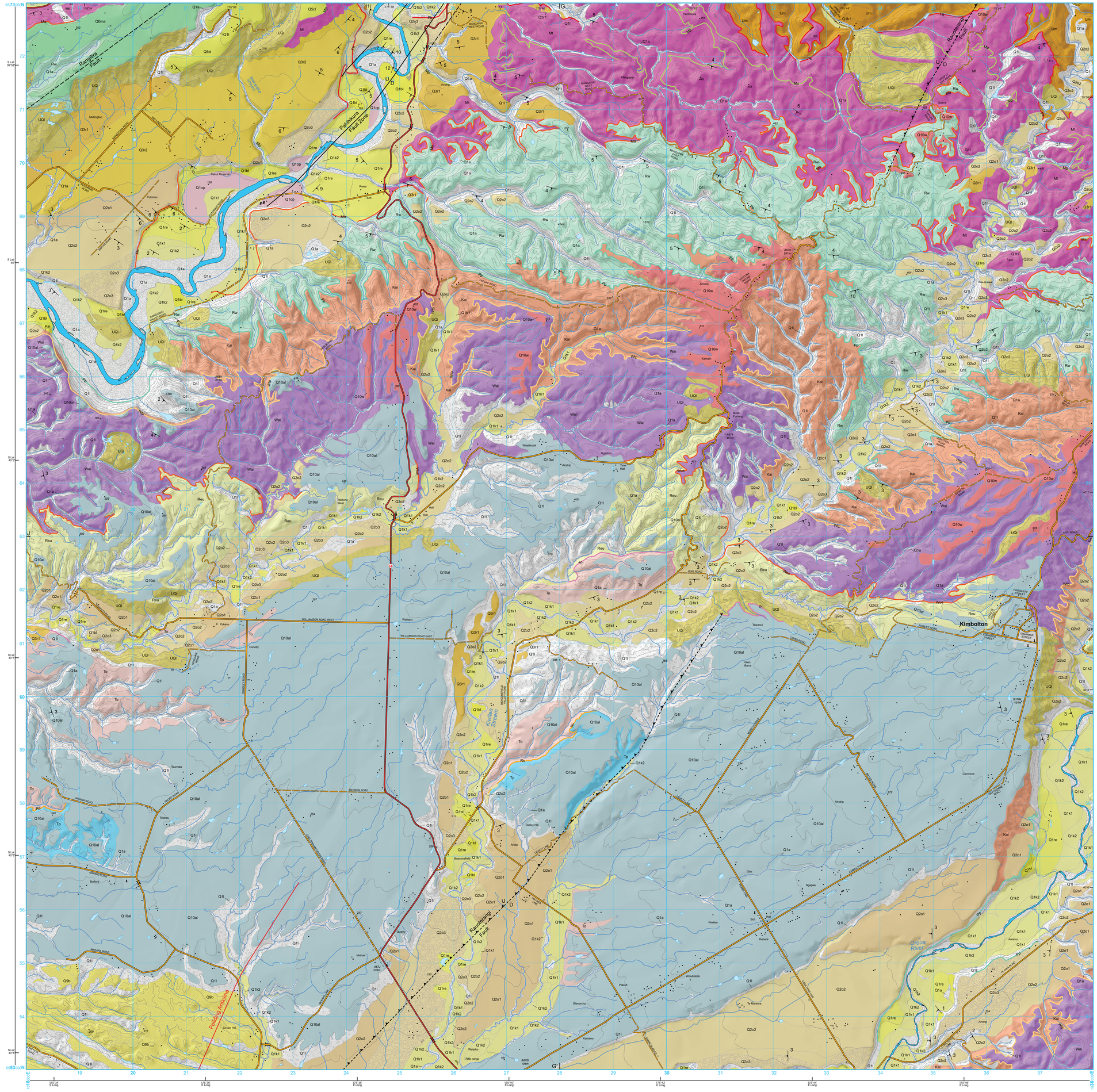
GEOLOGY OF CENTRAL RANGITIKEI



C. Rees

2020

1:25 000 Geological Map of the Central Rangitikei
Sheet 4 - Waituna


5573000N
5563000N
1818000E
1830000E
Rangitua Fault
Pakihikura Fault Zone
Raukawa Fault
Feilding Anticline
Kimbolton
Waituna Stream
Kiwitea Stream
Oroua River
Mangaweka
Hunterville
Marton
Bulls
Sanson
Feilding
Rangitikei River
Turakina River
Makirikiri Stream
Mangapipi Stream
Mangaonoho Stream
Mangaweka Stream
Mangaohoi Stream
Mangaonuku Stream
Mangaonuku Stream
Mangaonuku

EXTENDED GEOLOGICAL LEGEND

EASTERN WHANGANUI BASIN

Period | Epoch | Stage | Oxygen Isotope Stage | AGE Thousands of years | Tephra/ volcaniclastic and biostratigraphic marker beds

- QUATERNARY
  - HOLOCENE
  - PLEISTOCENE
    - CASTLECLIFFIAN
    - NUKUMARUAN
- NEOGENE
  - PLIOCENE
    - MANGAPANIAN
  - PLIO-PLEISTOCENE BOUNDARY
- HAWERAN

Oxygen Isotope Stage	Thousands of years	Tephra/ volcaniclastic and biostratigraphic marker beds
1	0	
	1.8	*TAUPO*
	12	
2	25.5	*KAWAKAWA*
3	50	*ROTOEHU*
	59	
4	71	
5	128	
6	186	
7	245	
8		
9	310	FORDELL AND UPPER GRIFFIN ROAD / LOWER AND MIDDLE GRIFFIN ROAD KAKARIKI
10	340	★*RANGITAWA*★ — *LAD Pecten novaezelandiae marwicki* phenotype
15	570	*ONEPUHI* — *Pecten novaezelandiae tainui* phenotype
16		
17	650	*KUPE* — *FAD Pecten novaezelandiae marwicki* phenotype
	Millons of years	
25	0.9	*KAUKATEA*
27	0.99	*POTAKA*
35	1 .19	*REWA*
53	1 .54	*MANGAPIPI*
54	1.56	*RIDGE*
	1.58	*PAKIHIKURA*
55	1.6	*BIRDGROVE*
	1.63	*MANGAHOU*
57	1.63	*MARANOA*
	1.64	★*OTOTOKA*★
58	1.65	*TABLE FLAT* — *LAD Patro undatus*
61	1.75	VINEGAR HILL
67	1.83	*WAIPURU* — *Mactra (Maorimactra) marwicki*
77	2.05	*MANGAMAKO*
82	2.17	*OHINGAITI*
94	2.4	★*HAUTAWA SHELL BED*★ — *FAD Zygochlamys delicatula*, *LAD Crassostrea ingens*, *LAD Phialopecten triphooki*, *LAD Globorotalia crassula*
104	2.58	
G2		
G14	2.8	*EAGLE HILL* / *KOWHAI*

★ *New Zealand Stage defining marker horizon*

WEST / EAST

	WEST	EAST
POUAKAI GROUP		We — WESTOE FORMATION (We); Ha — HALCOMBE CONGLOMERATE FORMATION (Ha)
SHAKESPEARE GROUP		Tp — MANGATAPU FORMATION (Tp); Rc — *RUAMAHANGA CONGLOMERATE MEMBER (Rc)*; To — TOKORANGI FORMATION (To); Tc — *TOMS CONGLOMERATE MEMBER (Tc)*
KAI IWI GROUP		Reu — REU REU FORMATION (Reu); Wos — *WAIOMIO SHELL BED MEMBER (Wos)*; Wai — WAIOMIO FORMATION (Wai); Msc — *MAKUHOU SHELL CONGLOMERATE MEMBER (Msc)*; Wtp — *WAITAPU SHELL CONGLOMERATE MEMBER (Wtp)*; Kai — KAIMATIRA PUMICE SAND FORMATION (Kai); De — *DEEPDEM CONGLOMERATE MEMBER (De)*; Pp — *POTAKA PUMICE MEMBER (Pp)*
OKEHU GROUP		Rw — REWA FORMATION (Rw); Mag — *MANGARA SHELL CONGLOMERATE MEMBER (Mag)*; Ma — *MANGAPIPI CONGLOMERATE MEMBER (Ma)*; Mt — MAKIRIKIRI TUFF FORMATION (Mt); Mp — *MANGAPIPI MEMBER (Mp)*; Pk — *PAKIHIKURA PUMICE MEMBER (Pk)*
MAXWELL GROUP		Um — UPPER MAXWELL FORMATION (Um); Ra — RATAITI FORMATION (Ra)
RANGITIKEI GROUP		Vi — VINEGAR HILL FORMATION (Vi); Ws — *WAIPURU SHELL BED MEMBER (Ws)*; Mo — MANGAONOHO FORMATION (Mo); Mm — *MANGAMAKO SHELL BED MEMBER (Mm)*; Or — ORANGIPONGO FORMATION (Or); Og — *OHINGAITI SAND MEMBER (Og)*; Mk — MAKOHINE FORMATION (Mk); Tu — *TUHA SAND MEMBER (Tu)*; Ti — TIKAPU FORMATION (Ti); Hs — *HAUTAWA SHELL BED MEMBER (Hs)*; Mg — MANGARERE FORMATION (Mg); Te — *TE RIMU SAND MEMBER (Te)*
PAPARANGI GROUP		Mw — MANGAWEKA MUDSTONE FORMATION (Mw)

Marine terraces and dunes

Q1m	Motuiti (Q1m) Q1 dunes
Q1f	Foxton (Q1f) Q1 dunes
Q5s	Mt Stewart dune sand (Q5s)
Q7n	Ngarino (Q7n) Marine terrace cover beds (gravel, sand, shells, peat, clay, loess and tephra)
Q9b	Brunswick (Q9b) Marine terrace cover beds (gravel, sand, shells, peat, clay, loess and tephra)
Q11ar	Ararata (Q11ar) Marine terrace cover beds (gravel, sand, shells, peat, clay, loess and tephra)

River terrace subsets

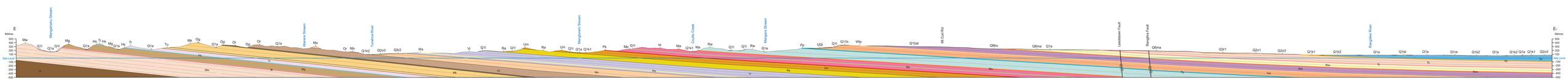
Q1k2	Lower Kakariki (Q1k2)
Q1k1	Upper Kakariki (Q1k1)
Q1op	Onepuhi (Q1op)
Q1re	Rewa (Q1re)
Q1bl	Bulls (Q1bl)
Q2o3	Lower Ohakean (Q2o3)
Q2o2	Middle Ohakean (Q2o2)
Q2o1	Upper Ohakean (Q2o1)
Q2vi	Vinegar Hill (Q2vi)
Q3r2	Lower Rata (Q3r2)
Q3r1	Upper Rata (Q3r1)
Q4pu	Putorino (Q4pu)
Q4po	Porewa (Q4po)
Q5cl	Cliff (Q5cl)
Q5gr	Greatford (Q5gr)
Q6ma	Marton (Q6ma)
Q8bu	Burnand (Q8bu)
Q10al	Aldworth (Q10al)
Q10w	Waituna (Q10al)

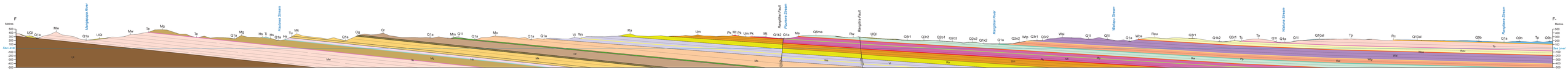
★*RANGITAWA*★

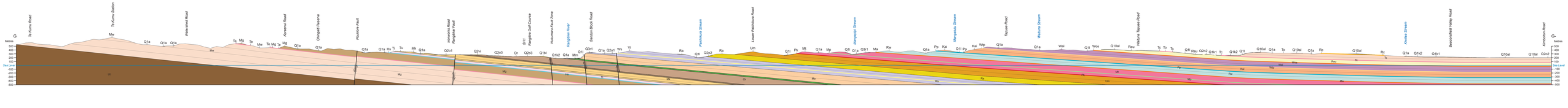
Landslides, Alluvium, Swamp deposits, Fill

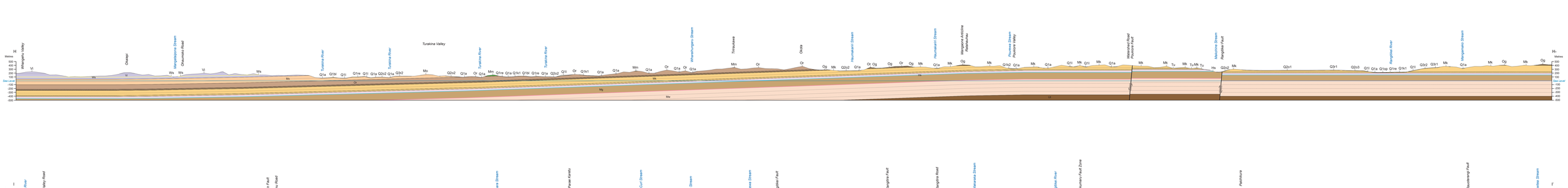
Q1n	Fill deposits (Q1n)
Q1a	Swamp deposits (Q1a)
Q1a	Coarse grained fluvial deposits (Q1a)
Q1a	Fine grained fluvial deposits (Q1a)
Q1l	Recent landslide deposits (Q1l)
uQl	Undifferentiated landslide deposits (uQl)

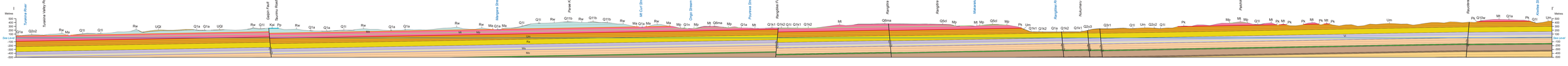
GEOLOGICAL CROSS SECTIONS - 1:25 000 GEOLOGICAL MAP SERIES OF THE CENTRAL RANGITIKEI

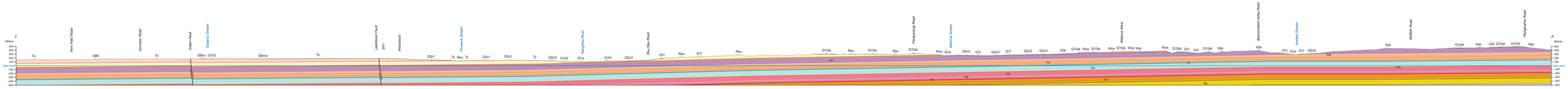


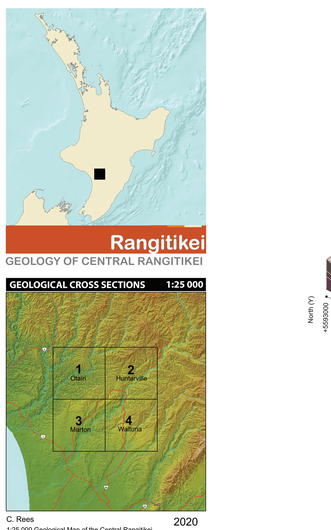








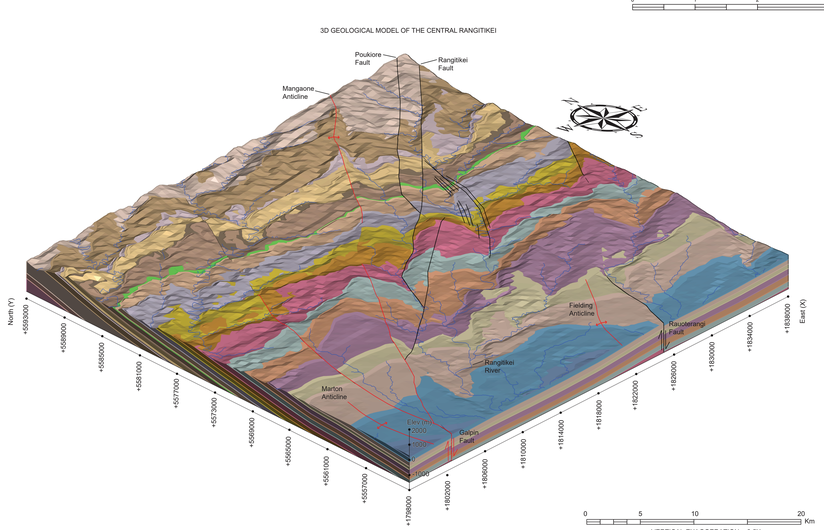




C. Rees 2020

1:25 000 Geological Map of the Central Rangitikei

Geological cross sections

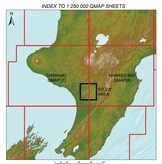


HORIZONTAL SCALE 1:25 000
VERTICAL EXAGGERATION=1X

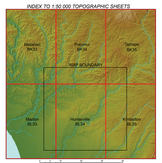
GEOLOGICAL UNIT CODES

Q1a - Late Quaternary alluvium
Q1l - Late Quaternary landslides
Q1k2 - Kakariki 2 Terrace
Q1K1 - Kakariki 1 Terrace
Q1op - Onepuhi Terrace
Q1re - Rewa Terrace
Q1til - Bulls Terrace
Q2o3 - Ohakean 3 Terrace
Q2o2 - Ohakean 2 Terrace
Q2o1 - Ohakean 1 Terrace
Q2vi - Vinegar Hill Terrace
Q3r2 - Rata 2 Terrace
Q3r1 - Rata 1 Terrace
Q4pu - Putorino Terrace
Q4po - Pourewa Terrace
Q5cl - Cliff Terrace
Q5gr - Greatford Terrace
Q6rma - Marton Terrace
Q7n - Ngarino Terrace
Q8bu - Burnard Terrace
Q9b - Brunswick Terrace
Q10al - Aldworth Terrace
Q10w - Waituna Terrace
Q11ar - Ararata Terrace
UQl - Undifferentiated Quaternary landslides
We - Westoe Formation
Ha - Halcombe Conglomerate Formation
Tp - Mangatapu Formation
Rc - Ruamahanga Conglomerate Member
To - Tokorangi Formation
Tc - Torra Conglomerate Member
Reu - Reu Reu Formation
Wos - Waiomio Shell Bed Member
Wai - Waiomio Formation
Wtp - Waitapu Shell Conglomerate Member
Kai - Kaimatira Pumice Sand Formation
Pp - Potaka Pumice Member
Rw - Rewa Formation
Ma - Mangapipi Conglomerate Member
Mt - Makirikiri Tuff Formation
Mp - Mangapipi Member
Pk - Pakihikura Pumice Member
Um - Upper Maxwell Formation
Ra - Ratarli Formation
Vi - Vinegar Hill Formation
Ws - Waipuru Shell Bed Member
Mo - Mangaonoho Formation
Mm - Mangamako Shell Bed Member
Or - Orangipongo Formation
Og - Ohingaiti Sand Member
Mk - Makohine Formation
Tu - Tufa Sand Member
Ti - Tikapu Formation
Hs - Hautawa Shell Bed
Mg - Mangarere Formation
Te - Te Rimu Sand Member
Mw - Mangaweka Mudstone Formation
Ut - Undifferentiated Utiku and Tahape Group

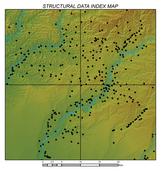
INDEX TO 1:250 000 QMAP SHEETS



INDEX TO 1:50 000 TOPOGRAPHIC SHEETS



STRUCTURAL DATA INDEX MAP



IMPORTANT SOURCES OF INFORMATION

Feldmeyer et al. (1943), Te Punga (1952, 1957, 1977), Fleming (1953, 1975), Milne (1968, 1973), Seward (1974, 1976, 1978, 1979, 1986), Anderton (1981), Pillans (1983, 1990, 1991, 1994, 2017), Bussell (1984), Potter, (1984), Kershaw (1989), Naish & Kamp (1995), Journeaux et al. (1996), van der Neut (1996); Pillans et al. (1996), Melhuish et al. (1996), Jackson et al. (1998), Abbott (1994), Carter & Naish (1998), Brackley (1999), Pillans et al. (2005).

BIBLIOGRAPHIC REFERENCE

Rees, C. (2020) The Hydrogeology of the Pourewa Sub-Catchment, Rangitikei, New Zealand. Unpublished PhD Thesis, Massey University, Palmerston North.

ACKNOWLEDGMENTS

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WARNING

This map series depicts an interpretation of the geology of the central Rangitikei based on both publish and unpublished geological information from a variety of sources together with data collected during a 2016-2020 field survey. These maps should not be used for building site assessment, land-use planning, engineering projects, quarrying operations or other work for which detailed site-specific investigations are required. Massey University accepts no responsibility for any losses arising from the use of this map series.

GEOLOGICAL CROSS SECTION LOCATION MAP